

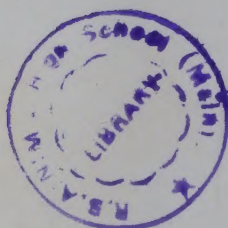
POPULAR SCIENCE

OUR WONDERFUL UNIVERSE

DINESH CHANDRA GOSWAMI

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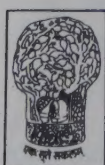
Popular Science

OUR WONDERFUL UNIVERSE

DINESH CHANDRA GOSWAMI



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Preface

Man has always been fascinated by the beauty of the sky. Since the earliest times, he has tried to follow the movements of the heavenly bodies and find some explanation for these. We are talking of the times when man did not understand the laws of these motions nor did he have proper instruments to take measurements. He, therefore, formed many incorrect ideas on the Universe and the phenomena around him. His inability to explain his observations gave birth to many myths and legends.

After many years, as early as the days of the Greek philosophers, the science of astronomy came into existence and developed. Many of the mysteries perplexing the human mind were explained and a somewhat clearer picture of the Universe emerged.

The Universe is, however, an inexhaustible source of mystery to scientists even today because there is still much that cannot be explained. The growth and development of man's knowledge about the Universe has been dealt with in some detail in this small book. It is hoped that this book will be able to generate an interest in the minds of the young readers and enthrall them to acquire more information about the Universe from various sources.

In writing this book I have taken extensive help from varied sources like works of astronomers and science writers, and a number of encyclopaedias. I gratefully acknowledge these sources. I am also grateful to Dr P.C. Neog who took considerable pains in preparing the manuscript through a word processor. I am thankful to

my wife Rupasree, son Pranjal, and daughter Pranali for bearing with me while I wrote this book. Pranjal also gave a few valuable suggestions for its improvement. Finally, I thank the National Book Trust, India, for undertaking the publication of the book so promptly.

Jorhat
20th January 1993

DINESH CHANDRA GOSWAMI

Our Wonderful Universe

It all began with a big bang thousands of millions of years ago. The matter that constitutes the cosmos, i.e. our Universe, was initially concentrated as a small 'cosmic egg'. Then an explosion of vast magnitude took place scattering the compressed, superdense matter in all directions. Our present-day Universe with clusters of galaxies, and the stars, planets, comets, pulsars and quasars—all were created out of this concentrated matter. The different elements that developed still have the motion that resulted from the explosion and are speeding away from each other at tremendous velocities.

The story of the Universe, as unfolded by the scientists, is a fascinating story. Bits of knowledge were accumulated through centuries to draw the picture of the Universe as we know it today.

When we look up at the sky on a clear night, we are fascinated by its ethereal beauty. The sky appears dotted with innumerable stars, some barely visible. We may even see a bright speck, the planet Mars. Once in a while a bright speck can be seen moving at a very high speed to vanish into nothing—it is a *shooting star*. Occasionally, we might be fortunate enough to see a *comet*—an object with a bright head and extending tail.

Apart from the many twinkling and a few stable points of light, there is the beautiful moon in the sky: it could be a thin arc or a full disk depending on the day of our observation.

Sometimes we see a faint glowing band across the

overhead sky. Known as the *Milky Way*, this band is made up of stars too far away or too small to be seen as separate points of light. The stars there are seen only as faint patches of light.

During daytime the bright sun rules over the sky.

Have you at any time wondered at the night sky? What are the stars? How far away from us are they? How did they come to the sky? For how long will they go on shining? What is there beyond them? Did these and many such questions bother you sometime? Have you ever wondered at the space in which these heavenly objects are seen and whether that space has a boundary, an end, or whether that is endless?

Man has always wondered at the sky since time immemorial.

The beginnings of science can be detected in Egypt and Babylonia. Star-gazing had probably something to do with it, because the first branch of science to develop was astronomy. Astronomical observations were even used to plot a calendar and the Babylonians were remarkably accurate in determining the length of the year and the periodicity of the lunar eclipse. But strangely, neither the Egyptians nor the Babylonians were able to go beyond these achievements.

"The earth we live on is a mound of land floating on the water of the underworld. During the day the sun-god Ra, travels east to west across the heavenly ocean. At night, when Ra is in the underworld, we see the star-spangled body of the sky-goddess Nut, arching over us"—thus runs an ancient Egyptian story. In our mythology also the sun-god is depicted as travelling through the heaven during the day in his chariot.

All the early civilisations had such stories to tell to explain the unexplainable. Man's quest continued all throughout the history of mankind, and it is because of his perseverance that today we know so much about the wonderful Universe. The quest continues to this day—for

the solution of one mystery has led to the generation of another more complex mystery. And we are as fascinated today with the Universe as our ancestors were millions of years ago.

It was quite natural for the people of ancient times to suppose that the sky was simply a hard canopy in which the shining heavenly bodies were fixed. But, during 6th to 4th century B C, the Greek astronomers realised that there was more than one canopy because, they observed that the 'fixed stars' moved around the earth in a body, and their relative positions did not seem to change. But, the sun, the moon and the five bright objects—Mercury, Venus, Mars, Jupiter and Saturn changed their relative positions to move in separate paths with different speeds. The Greek astronomers called these bodies, *planets*. The word 'planet' was derived from the Greek word meaning 'wanderer'. These astronomers were convinced that these seven bodies were different from the stars.

It was the Greeks who tried to explain the heavenly happenings like the day and night, the seasons in the year, and the eclipses of the sun and the moon. Theoretical astronomy, therefore, began with them.

The Far-Sighted Men of Astronomy

It was believed by everybody that the earth was the centre of the Universe. Some Greek astronomers, however, chose to differ. In the 5th century B C, the Greek astronomer, Anaxagoras, said that the sun, the moon and the planets were not simply lights in the sky but were solid bodies like the earth. That the earth was not a stationary body, but it rotated about itself (i.e. spinned like a top) was another idea put forth for the first time by a Greek philosopher, Heraclides, in the 4th century B C.

Some great Indian mathematician-astronomers also made significant contributions to the growth of astronomy. Giants among these scholars were, in chronological order,

Aryabhata I, (b. A D 476) Varahamihira (499-587), Brahmagupta (b. 628), Bhaskara I (b. 629), Aryabhata II and Bhaskara II (also known as Bhaskacharya, b. 1114).

Aryabhata I deduced that the earth was round, and day and night were caused as the earth rotated on its axis. He said that the moon itself was dark and it shone because of sunlight. He also stated that eclipses were caused because of the shadows cast by the earth and the moon.

Varahamihira, like Aryabhata, declared that the earth was spherical. He was the first to say that some force might be keeping the bodies stuck to the round earth. This was surely a hint on the theory of gravitation several centuries before Newton.

Another great mathematician-astronomer, Brahmagupta, criticised Aryabhata because the latter said that the earth rotated on its axis. But he believed that the earth was round.

Bhaskara II tried to explain the true motions of the heavenly bodies as the motions along some small circles whose centres moved along the circumference of a bigger circle. He succeeded in explaining the motions of the sun, the moon and the planets with the help of some models and astronomical instruments. Bhaskara also wrote a manual for easy and accurate calculations of astronomical events with the help of which an accurate calendar was devised.

The astronomer-king, Raja Sawai Jai Singh II (1699-1743), built Jantar Mantar (observatories) at Delhi, Jaipur, Ujjain and other places to make astronomical observations.

The first scientific measurement of a cosmic distance was made by Eratosthenes of Cyrene around 240 B.C. He observed that on 21 June at noon, when the sun was exactly overhead on the city of Syene in Egypt, it was slightly away from the zenith at Alexandria which was 800 km to the north of Syene. Eratosthenes concluded that this was because the earth was curved; not flat. From the

length of the shadow at Alexandria, he calculated the earth's curvature at two points at a distance of 800 km. With this then he calculated the circumference and the diameter of the earth. It is really astonishing that he could arrive at almost the present-day figures for these two parameters. He found the earth's diameter to be about 12,000 km and the circumference about 40,000 km. Many astronomers were not ready to accept these figures. It was only after the first circumnavigation of the globe, during 1521-1523, that these figures could be established beyond doubt. By the time of Plato (427-347 B C) and Aristotle (384-322 B C), the earth was accepted as a sphere. But, it was still believed to be the centre of the Universe and all heavenly bodies were thought to move around the earth.

Once the parameters of a heavenly body were calculated by an astronomer, many astronomers devoted their time and energy to the calculation of the distances of heavenly bodies, such as the moon and the other known planets.

Distance of the Moon

Around 150 B C, Hipparchus of Nicaea calculated the distance of the moon. A method was suggested by the great Greek astronomer, Aristarchus of Samoa (about 270 B C) based on the relative sizes of the moon and the earth's shadow on it during the time of eclipse. By a geometrical construction, Hipparchus calculated the moon's distance from the earth. From the figure of 12,000 km for the earth's diameter, as given by Eratosthenes, this distance came to 3,84,000 km—a figure almost tallying with the modern figure of 3,84,400 km. Hipparchus compiled a catalogue of about 1,000 stars, with his naked eyes as the only pair of optical instruments. He also discovered that the earth has a *precession*. This means that a gradual change takes place in the direction of the earth's axis in space.

Aristarchus even constructed an accurate geometrical

diagram to find out the distance of the sun from the earth. But at that time, there was no instrument to measure the small angles accurately. He was, therefore, led to conclude, though erroneously, that the distance of the sun from the earth was 20 times the earth-moon distance. But, today we know that it is 400 times the earth-moon distance.

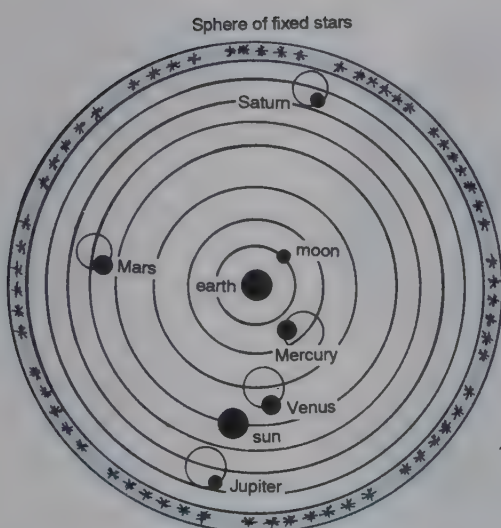
Aristarchus, however, made a revolutionary contribution to man's science and philosophy by announcing, for the first time, that the earth moved round the sun. Aristarchus was sure that the sun was much bigger than the earth. He reasoned that it was illogical to think that the large sun moved round a small earth.

The theory given by Aristarchus that the earth moves round the sun through the vast emptiness of space was contrary to man's common sense and not easily acceptable to all. It was also too revolutionary to be accepted by the astronomers who believed the earth to be the motionless centre of the Universe. For 400 years no one listened to Aristarchus. No one listened to him for centuries thereafter.

In about 150 A.D., Claudius Ptolemy, the Greek astronomer from Alexandria, compiled all the knowledge in astronomy and science gathered by mankind till his time in a series of books. This series may be regarded as the first science encyclopaedia. He very carefully summarised the achievements of the ancient Greek astronomers. The work was translated into Arabic with the title *Almagest*. In his *Almagest*, Ptolemy recorded the great works of the earlier astronomers.



Claudius Ptolemy.



Ptolemy thought that the earth was at the centre of the Universe around which the planets moved.

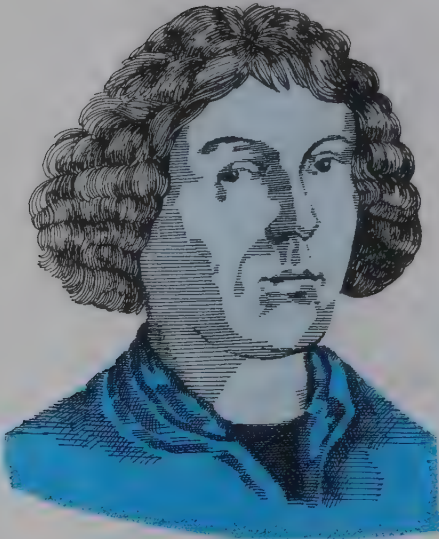
Ptolemy based everything on the commonly believed earth-centred theory. In his system, known afterwards as the *Ptolemaic system*, the earth was the centre of the Universe around which the sun, the moon and all the planets moved. Enclosing all this was a great sphere on which the stars were fixed. The sphere also rotated around the earth taking with it all the stars. He believed that the earth did not rotate, for if it did then clouds would not move eastward because the air would be blowing in the other direction all the time.

Although the Ptolemaic system could not accurately account for the motions of the heavenly bodies as seen by man, nobody challenged it for nearly 1,400 years.

The Revolutionary Idea

Then in 15th century A D, a great challenge was brought to astronomy by a Polish priest-astronomer, Nicolaus Copernicus (1473-1543).

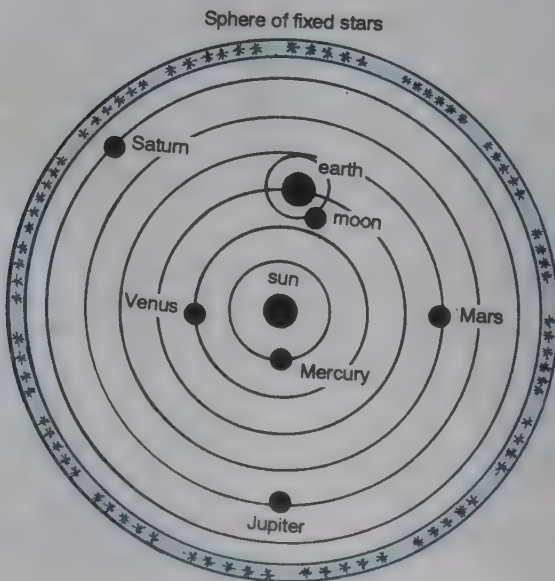
In 1543, Copernicus published a book entitled *De*



Nicolaus Copernicus.

revolutionibus orbium coelestium which meant 'On the revolution of the heavenly bodies'. In the book Copernicus gave a theory in which he placed the sun as the centre of the Universe, with the earth and other planets revolving round it. He stated that the stars in the vast limitless sky surrounded the sun and the planets. He also stated that the earth rotated about its axis and this accounted for the occurrence of day and night.

Copernicus was a professor of astronomy at the University of Rome where he taught the Ptolemaic system of astronomy. But, after observing the motions of the heavenly bodies and doing a lot of mathematical



Copernicus believed that the earth, moon and planets revolved around the sun.

calculations, he became convinced that Ptolemy's ideas were wrong. The earth could not be the centre of the Universe, and it was illogical to think that the big sun and the planets would revolve round the small earth. Copernicus pointed out that the clouds and all the rest of the atmosphere were really part of the earth and were rotating along with it.

It took Copernicus several years of painstaking work to arrive at his theory. But to get the world to accept such a new idea was a very difficult process, because this new idea would shatter the long-established religious beliefs. At first Copernicus tried to win the elite by conversation and discussion only. But as was expected, the contemporary men of learning opined that Copernicus was trying to turn the whole astronomy upside down. He was also accused of working against religion. The priests were highly offended to learn that Copernicus was trying to dethrone the earth as the centre of the Universe.

Copernicus, therefore, decided to publish his idea in the form of a book. He hoped that a section of the learned people would at least examine the theory and by and by accept it. He even dedicated the book to Pope Paul III with the hope that this would win his approval. The publisher in Nuremberg was terrified of the revolutionary nature of the text. He got a preface written by someone claiming that it was not a book of science, but a 'playful fancy'.

Copernicus would have been very unhappy at such a description of his life's work, but he never actually read the printed book. A copy of the book was placed in his hands when he was on his death-bed, i.e. on 21 May 1543.

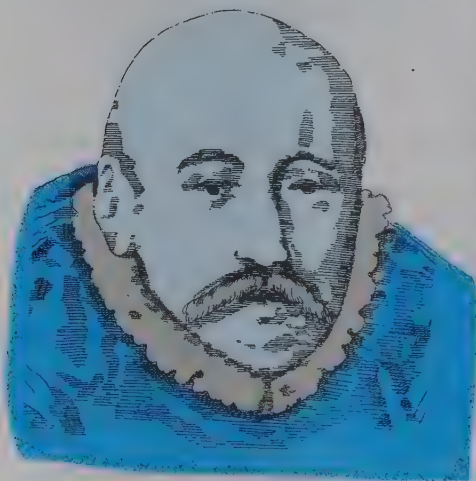
Copernicus' work formed the foundation for all future work in astronomy. All future astronomers like Galileo, Tycho Brahe, Kepler, Newton and Einstein based their work on Copernicus' theory.

A Sound Scientific Method

Moreover, future astronomers and scientists were

encouraged by his example to challenge the old and established ideas when they came across some new concepts and explanations. Copernicus also established a sound scientific method based upon careful observation, analysis and explanation and then acceptance of the new and challenging ideas with an open mind.

By placing the sun at the centre of the solar system, Copernicus took a bold step forward in his quest for knowledge about the Universe. But, Copernicus could not find out the distance of the planets. He used the known value for the distance of the moon, but did not have any knowledge about the distance of the sun.

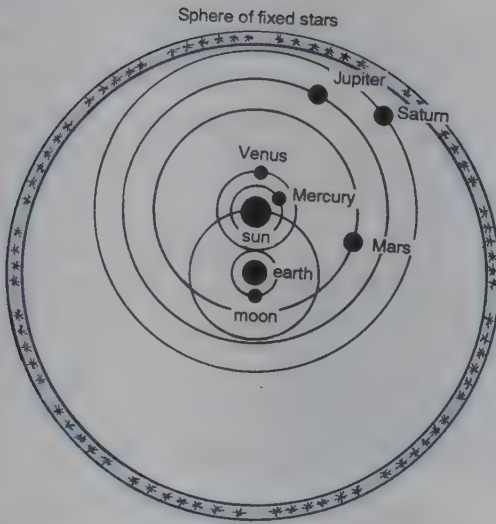


Tycho Brahe.

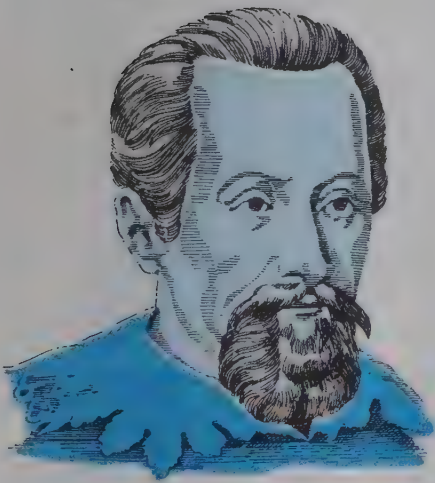
Copernicus was followed by Tycho Brahe (1546-1601), a Danish nobleman, who developed some measuring instruments for his calculations. Brahe refused to believe that the earth was not the centre of the Universe. He suggested, instead, that the other planets revolved around the sun, and that the sun in turn revolved around the earth.

Brahe made a large number of observations of the sky and carefully recorded his data in volumes after volumes of his notebooks. He collected so much data about the motion of the planets that their orbit could be determined. These data were later used by his student and assistant, Johannes Kepler (1571-1630), a German astronomer and mathematician.

Kepler worked out the laws governing the planets. He showed that the planets revolved round the sun in elliptical (oval) orbits and not in circular orbits. He also drew a schematic diagram of the solar system. This means



Tycho Brahe was convinced that the earth was the centre of the Universe.

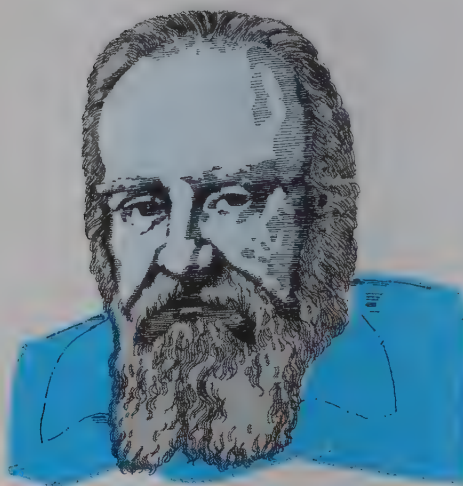


Johannes Kepler.

that the diagram was drawn to the scale. So if one knew the distance between any two objects in the diagram, the distance between the other objects could be found out. Kepler's diagram, therefore, became a valuable document for calculating the distances of the planets. Kepler also described the varying speed of a planet in its orbit. When a planet is nearest to the sun it is moving the fastest, and when farthest from sun, it is

moving the slowest. Kepler was coming close to the idea of gravitation without explicitly announcing it.

Another very remarkable name in the history of astronomy was Galileo Galilei (1564-1642). In 1609 this great Italian built the first practical telescope and looked up at



Galileo Galilei.

the sky through its lenses. He was the first man to provide visual evidence of the solar system. Through his telescope which had a lens of one inch (2.5 cm) diameter, Galileo could see the mountains on the moon and the spots of the sun. (The last was a bad mistake. He looked at the sun directly with the telescope and blinded himself for a while). He saw four moons circling Jupiter—as if it was a miniature solar system. He also observed through his telescope that the planet Venus goes through phases, like the moon does. The last two observations convinced him that Copernicus was right.

When Galileo began to teach and propagate the theory given by Copernicus that the earth moves round the sun, at the Padua and Pisa universities, the church summoned him for an explanation. But, Galileo, due to his friendship with Pope Paul V and some other influential friends, was able to get off with a warning when he agreed that he would not teach or defend the Copernican theory. This happened in 1616.

This could silence Galileo for a few years only. In 1632, he broke the silence by publishing a book, *Dialogue Concerning the Two Principal Systems of the*



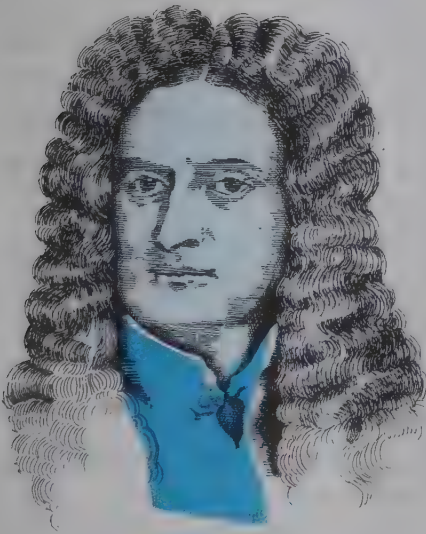
Two of the Galileo's early telescopes.

World. In this book he narrated, in the form of conversations and arguments, the flaw in the geocentric (earth-centred) Ptolemaic system as compared to the heliocentric (sun-centred) Copernican system.

He was again called before the 'court'. This time his crime was considered to be very grave: he not only propagated a theory against what was preached in the holy books but, also broke his own agreement with the church. It was decided that Galileo would have to publicly swear that his beliefs were false. He would also have to abandon further work in science and suffer confinement. But, on account of indifferent health, he was allowed to remain in a small house, guarded by sentries.

The 'court' compelled him to confess his error. Today we realise that his error was actually not an error but a great truth for all times to come. Galileo knelt before the 'court' and confessed. But, some people said afterwards that they heard him muttering inaudibly, "*E pur si muove*", meaning "but, still it moves (round the sun)".

Galileo became blind in 1638 at the age of 74, when another of his books on mechanics and motion was published from Holland. He was dishonoured by the church and when he died in 1642 at the age of 78, no public funeral was permitted. But, this great scientist, apart from his other contributions in the fields of motion and mechanics, put astronomy on a firm footing.



Isaac Newton.

In the year Galileo died, another great scientist and astronomer was born in England. He was Sir Isaac Newton (1642-1727). In the 1660s, Newton developed the law of gravitation. The law

states that all objects are attracted to all other objects by the force of gravitation. On the basis of this law, Newton could explain why the heavenly bodies moved as they did. He showed that because of the gravitational attraction, the moon and the planets moved in elliptical orbits.

Moreover, Newton was the first scientist to say that the stars are suns, like our own sun, and they are at very great distances. These scientific explanations of the earth, sun, moon and planets lasted without change until the 20th century. By the time of Newton's death, he had become one of the most honoured of all scientists. Before him nobody had any clear idea about the stars. In ancient mythology, the stars were considered as 'fiery balls'. Sometimes they were even thought to be holes in the sky through which light from a great fire beyond came towards us.

Telescopes and Clocks

Newton also built a telescope based on a principle different to that used by Galileo. Man's knowledge of the Universe grew gradually because of two important inventions: the telescope and the clock.

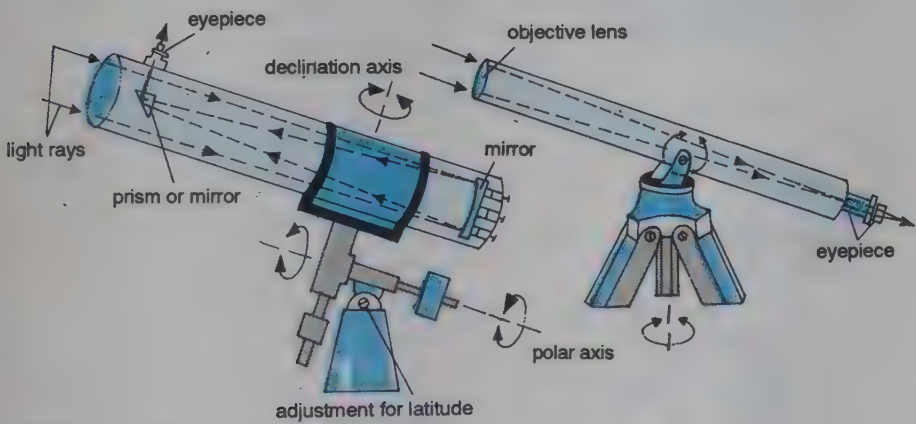
At the beginning of the 17th century Galileo heard that a Dutch optician had put together a concave and a convex lens in such a way that if one looked through the system, distant objects seemed to be nearer and distinct. Using the idea, Galileo built his own telescope.

As has been said earlier, the lens of Galileo's telescope was only one inch (2.5 cm) in diameter. But, it could magnify objects 30 times and through it Galileo discovered the four moons of Jupiter and the different phases of the Venus. He also observed the mountains in the moon and the sunspots through it. Galileo's telescope was a simple two-piece system. It had an objective lens that focused the light from the object and an eyepiece lens that magnified the focused image. Such telescopes are known as *refracting*

telescopes.

Objects which were earlier mere points of light in the sky were transformed, when viewed through the telescope, into solid bodies. New wonders were also revealed in the sky. It is not surprising then that more interest was devoted to the development and improvement of the telescope.

Newton took up the development of telescopes on an altogether new line. He developed a telescope that used a mirror. The mirror received the light from the object under observation and focused it. Since a mirror is used here to reflect light, these telescopes are called *reflecting telescopes*.

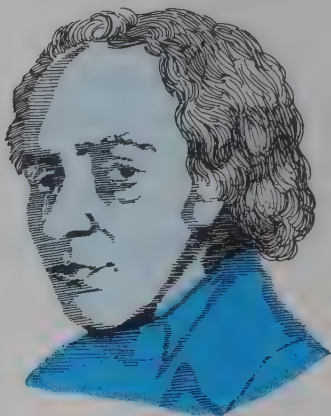


Reflecting and refracting telescopes.

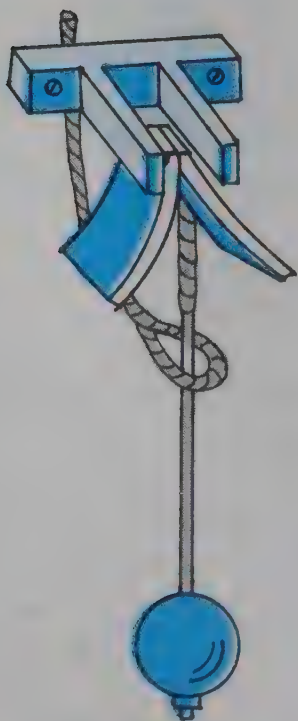
A reflecting telescope requires a large mirror to collect sufficient light from distant objects. But, during Newton's time it was difficult to make a large mirror without defect. That was why reflecting telescopes of good efficiency could not be built for quite some time and astronomers had to continue with refracting telescopes only. Astronomers, therefore, tried to develop better refracting telescopes with bigger lens systems.

Although better telescopes were gradually built, one device was still lacking. There were no instruments in the

hands of astronomers and scientists to measure time accurately. It was, therefore, not possible for them to keep an accurate record of events when these took place. It was also not possible to carry out further measurements.



Christian Huygens.



Huygen's pendulum.

The Dutch mathematician, Christian Huygens (1629-1695), developed a pendulum clock towards the end of the 17th century. Huygens was interested in astronomy from his childhood. He realised that the study of the heavens was not accurate because the astronomers did not have a device that could precisely measure time when a heavenly body was observed. Galileo had suggested that a pendulum might be used to keep time. Huygens considered this idea seriously. In 1657 he built a clock. The hands of the clock moved through a particular distance with each swing of the pendulum. The hands of the astronomers, as well as of the other scientists, were now strengthened. The movement of the heavenly bodies could now be accurately timed.

Earlier telescopes were improved and modified. Newer and better clocks were gradually built. With these two powerful devices—the

clock and the telescope—astronomy started progressing at a fast pace.

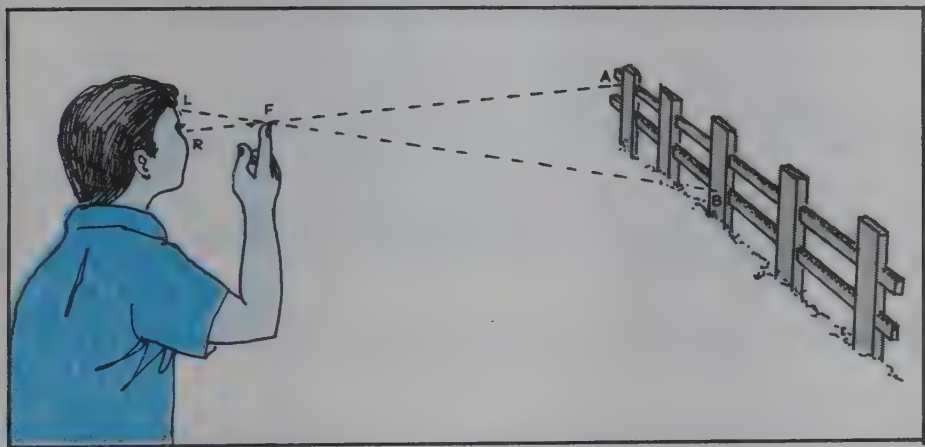
Apart from these two physical instruments, the law of gravitation propounded by Newton also strengthened the hands of astronomers. Observation through the telescope, measurement of time with the clock and deductions made on the basis of the law of gravitation led to a clearer and more accurate picture of the Universe. For nearly 2,000 years theories propounded by Aristotle had seemed perfect and nobody could contradict them. But, with the new physical and mental tools, astronomy made new advances. And since then the perspective of the Universe has begun to change.

Heavenly Distances

Although the Greek astronomer, Eratosthenes, calculated the diameter and the circumference of the earth and Hipparchus calculated the earth-moon distance, no further progress was made in the measurement of heavenly distances. Kepler drew a schematic diagram of the solar system to the scale from which the distances of the planets could be calculated. But these calculations were rough. It was very difficult even to guess the distances of the stars. All that astronomers like Copernicus could say about the distances of the stars was that they were very far away. They were able to say this because the positions of the stars and the distances between them did not seem to change at all from one time of the year to another. This can be better understood if you imagine yourself in a moving car. When you look at the horizon you notice that objects nearer to you change their position against the background of more distant objects. In the same way, you are travelling through space as the earth moves around the sun. The stars close to you would appear to shift their position against the background of more distant stars if observed throughout the year. This apparent change of position with background stars is called *parallax*.

The Parallax Method

Soon a method for measuring the heavenly distances was developed. The method involves the use of parallax. Most of us have been using this while passing a thread through



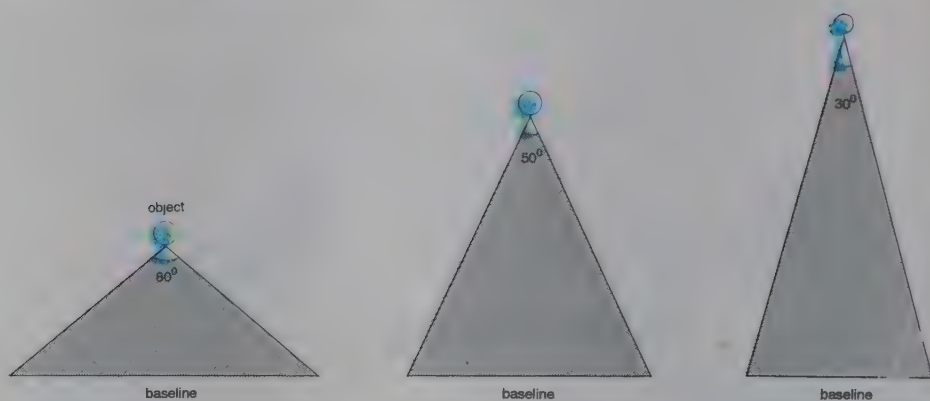
Parallax of a finger against a fence. With the right eye R, finger F is seen at A, but it shifts to B when seen with the left eye L.

the eye of the needle. In this, we assess the distance of the eye of the needle from the angle made on it by our two eyes. It is difficult to pass the thread through the eye of the needle with one of our eyes closed, because the needle's eye cannot make an angle on only one of our eyes.

In order to have a feel of the parallax method, hold one of your fingers at a distance of ten centimetres from your eyes. First see the finger against the wall or some other backdrop with your right eye closed. Then, see the finger again with just your right eye. You will notice that the position of your finger changes on the backdrop.

Now, move the finger away from the eyes, say, to your arm's length, and repeat the experiment. You will still notice the shift of the finger against the background. But, the shift will be far less because the angles made by the object at your eyes become smaller and smaller as the object moves away from the eyes. From such an angle only we get a feel at our eye muscles and judge the distance of the eye of the needle while passing the thread through it.

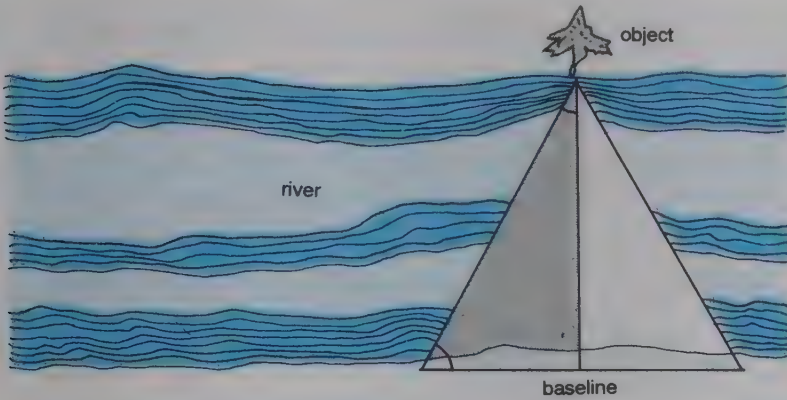
If the distance between the object and the eyes is



For the same baseline, the farther an object is, the lesser is the parallax.

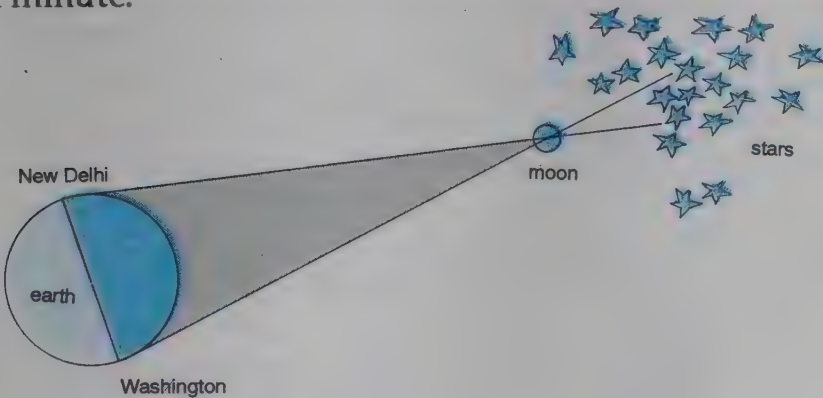
further increased, the shift will be hardly discernible. The 'baseline' formed by the distance between the two eyes becomes too small for a distant object to give a measurable parallax or shift. The baseline, therefore, will have to be widened. This can be done easily. All we have to do is to take the observation from one point and then move to another distant point and take an observation of the object from that point. The parallax will now be large enough to be measured easily. Scouts are trained to measure the width of a river or the distance across a riverine. For this they select an object on the other side of the river or riverine. Then, fixing a known length on their side as the baseline, they measure the angles formed at the object by the two points at the two ends of the baseline. With the help of simple geometry one can calculate the distance of the object when the length of the baseline is known.

For measuring the distance of the moon also we can apply the same method. Let us observe the moon from one telescope at, say, New Delhi and another at, say, Washington, D.C. The straight line connecting the two cities will be the baseline—the distance will be known. Now the parallax of the moon, i.e. the shift in the moon's position seen against the fixed starry background and the length of the baseline will enable us to calculate the distance of the moon.



Finding out distance by the parallax method.

The shift of a heavenly body against the background is measured in degrees or fraction of degrees, i.e. minutes and seconds. One complete circuit around the sky is 360 degrees. One degree is 360th part of that. One minute is a one-sixtieth part of a degree and one second is one-sixtieth of a minute.

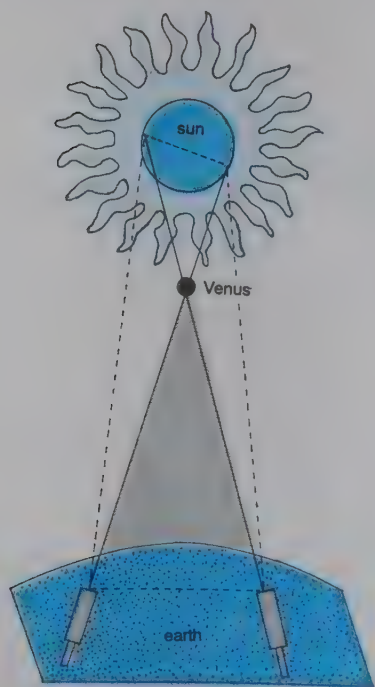


Parallax of the moon.

The shifts or parallax made by the heavenly bodies against the background of the stars becomes less and less as the distance of these bodies from us increases. If a heavenly body is observed from two points at directly opposite sides of the earth, i.e. if the baseline is about 12,000 km, half of the resulting angle of parallax is called *geocentric parallax*.

The moon's geocentric parallax is 57 minutes, i.e. three minutes less than a complete degree. But, this is easy enough to be measured even with the naked eye. Claudius Ptolemy calculated the moon's distance from the earth by observing the parallax with his naked eyes. But, with the same baseline when one measured the parallax of the sun or of the planets, it was found to be very, very small. From these observations one could only conclude that these bodies were many, many times away than the moon. But no quantitative measurement was possible.

Trigonometry alone could not help in measuring the distances of other heavenly bodies, during the era of the naked eye, because of the minute angles of parallax involved. But, with the beginning of the era of the telescopes this problem could no longer hinder the progress of astronomy.



Measurement of the
parallax of the sun.

In 1752 the planet Venus was to pass across the disk of the sun. Several years earlier, the English astronomer, Edmund Halley (1656-1742), had suggested that the passage of Venus across the sun's disk should be observed carefully from several far away points. The time that Venus would take to pass across the sun's disk, as observed from different stations, could be used to calculate the sun's parallax. From the parallax the sun's distance could be calculated. Using that as the basic data, all other distances of the solar system could be calculated.

Astronomical Unit (A.U.)

The sun's average parallax was found to be 8.8 seconds of an arc. On basis of this the distance of the sun from the earth was calculated. This calculation was modified several times, once with the parallax measured in 1931, when an asteroid, Eros, passed across the sun's disk. The average distance of the sun now stands at $14,94,50,000 \pm 17,000$ km. The diameter of the sun was calculated to be 13,90,600 km, which is about 109 times the earth's diameter.

This average distance of the sun from the earth is called an *astronomical unit* (A.U.). Other distances of the solar system are expressed in terms of this unit.

Mars, the planet next to earth, is at a distance of 227.94 million km (roughly 22.8 crore km) from the sun. In astronomical units, this distance is 1.52 A.U. Jupiter is at a distance of 778.34 million km or 5.20 A.U., while Saturn is 1427.01 million km or 9.54 A.U. away.

With every new discovery of an outer planet, the realm of the solar system expanded. Uranus was found to be 2869.6 million km or 19.18 A.U. away, Neptune's mean distance was found to be 4496.7 million km or 30.06 A.U., and Pluto's mean distance was found to be 5,907 million km or 39.52 A.U.

But, Pluto's orbit is highly elongated, and so Pluto moves to the extreme distance of 11,680 million km or 79 A.U. also.

Some comets are known to go to even greater distances away from the sun.

By the year 1830 the solar system, with its nine planets, several satellites and innumerable comets, was known to be several billions of kilometres away in space. But the solar system with the sun at its centre occupies only a minute part of the Universe—the stars of the Universe are still much, much beyond and, therefore, the Universe must indeed be very big.

How Far is a Star?

Actual measurement of the distance of the star could not be carried out till 1838. Astronomers knew since the beginning that the stars were scattered in the Universe. Some stars were somewhat nearer to us, others were far, far away. So, the stars showed some parallax against the background of the stars which were farther away. However, these parallaxes were so insignificant that they could not be measured with the available instruments.

Astronomers thought that if the baseline could be elongated further, then the parallax could perhaps be measured. But, the baseline had already been elongated as far as practicable—to two farthest points on the surface of the earth, i.e. to about 12,000 km. Could it be elongated any further?

A way out was soon found. The earth moves round the sun in an enormous ellipse. If one can go to the two ends—two farthest points—of this ellipse, the baseline would be very long. It would be about 300 million km or 30 crore km. The problem was—how to go to the two ends of the elliptical orbit of the earth. Would one need a spaceship? A man-made spaceship was a thing of science fiction in those days, hence, no wonder, people ridiculed the idea at the outset.

However, a natural spaceship was readily available. One had to take an observation of a nearby star against the background of distant stars, wait for six months, and then take another observation of the star. The method was theoretically all right. But, in practice, the parallax was extremely small. It could not be measured by the telescopes available in those days. The only conclusion that astronomers could draw was that the stars were far, far away.

Gradually, improved and more powerful telescopes were built. An amateur German astronomer, Friedrich Wilhelm Bessel (1784-1846), chose a star known as 61

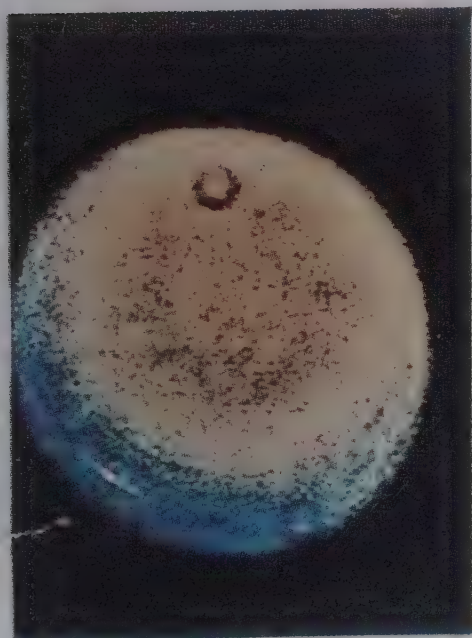


Plate IV The US spacecraft Voyager 2 took these photographs when it flew past Jupiter (*upper left*) in July 1979, Saturn (*upper right*) in August 1981, Uranus (*lower left*) in January 1986 and Neptune in August 1989 (*Courtesy: USIS*).



Plate V The planet Venus as photographed from a spaceship.

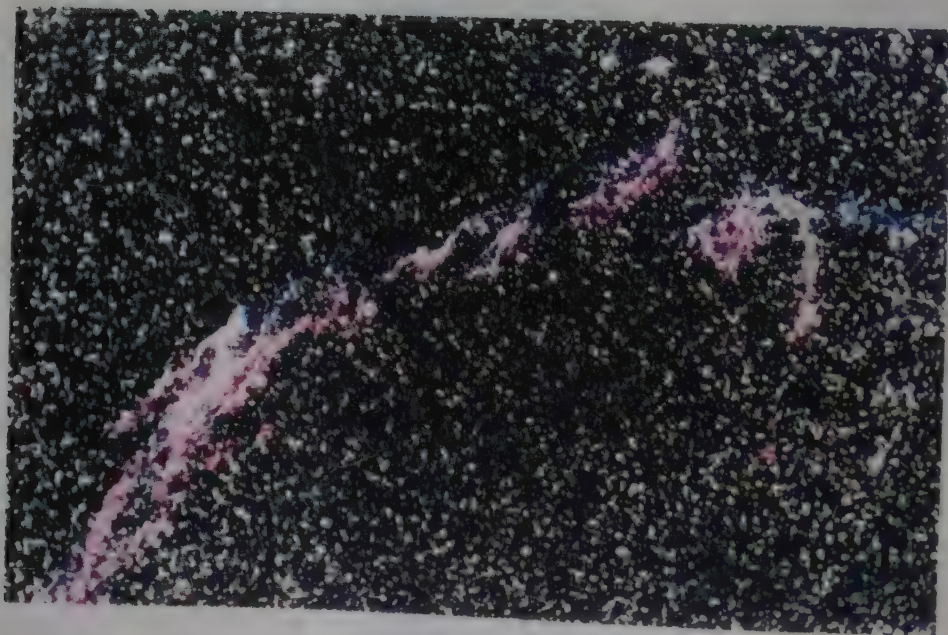


Plate VI A view of the Milky Way.

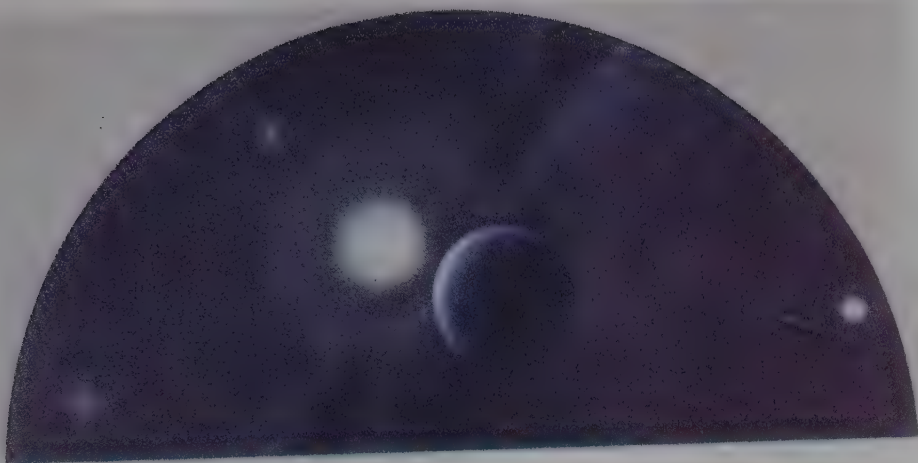


Plate VII Artist's conception of the sun and earth with the Milky Way streaking beyond (*Courtesy: Smithsonian Institution, USA*).

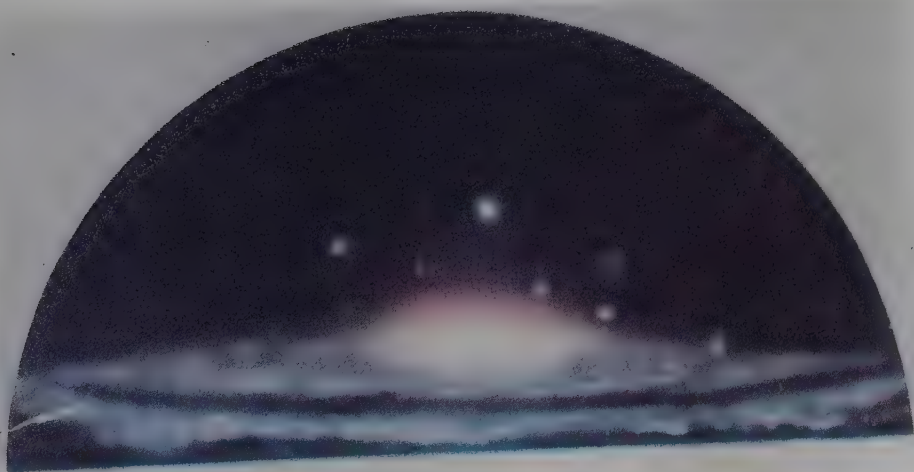


Plate VIII Artist's conception of our Milky Way Galaxy. The sun is at a distance of 30,000 light years (present estimate is 23,000 light years) from the centre of the Galaxy. Astronomers believe that stars are born in the dusty gas clouds in the outskirts of the Galaxy (*Courtesy: Smithsonian Institution, USA*).

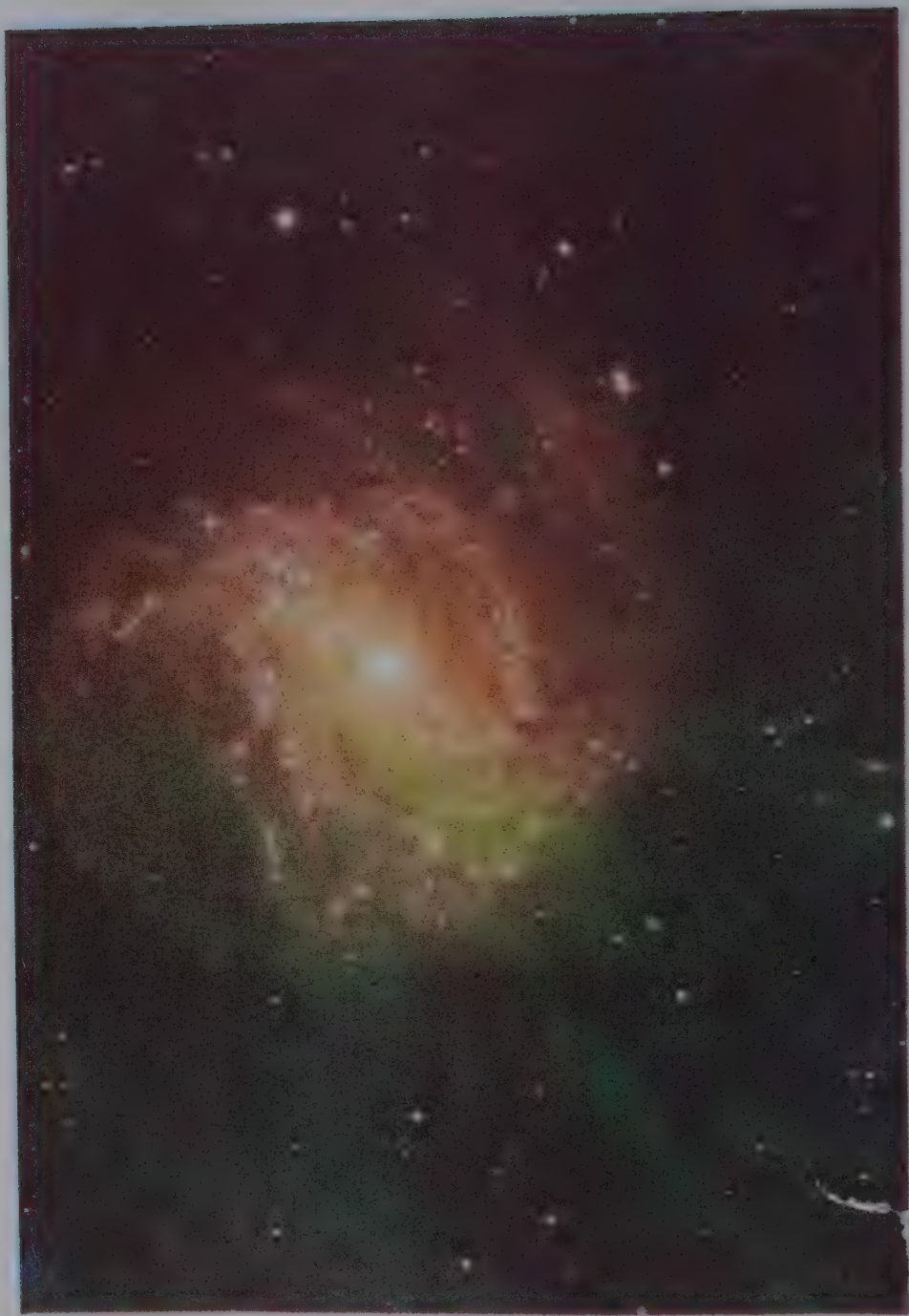


Plate IX The Messier 83, like our own Milky Way, is a spiral galaxy. At its hub, a dense concentration of stars and gas pinpoints a conspicuous nucleus. Within the brilliant clouds of gas new stars are forming. About three-quarters of the galaxies in the Universe are spiral (*Courtesy: Spectrum*).



Plate X A 32-metre, 100-ton radio telescope at Lord's Bridge, just outside Cambridge, UK. This telescope linked with six others mimics a single radio telescope with a dish 200 km across (*Courtesy: Spectrum*).



Plate XI The Very Large Array, a set of 27 movable radio antennas spread over 32 km of New Mexico desert. The set acts like one enormous radio telescope (*Courtesy: Smithsonian Institution, USA*).

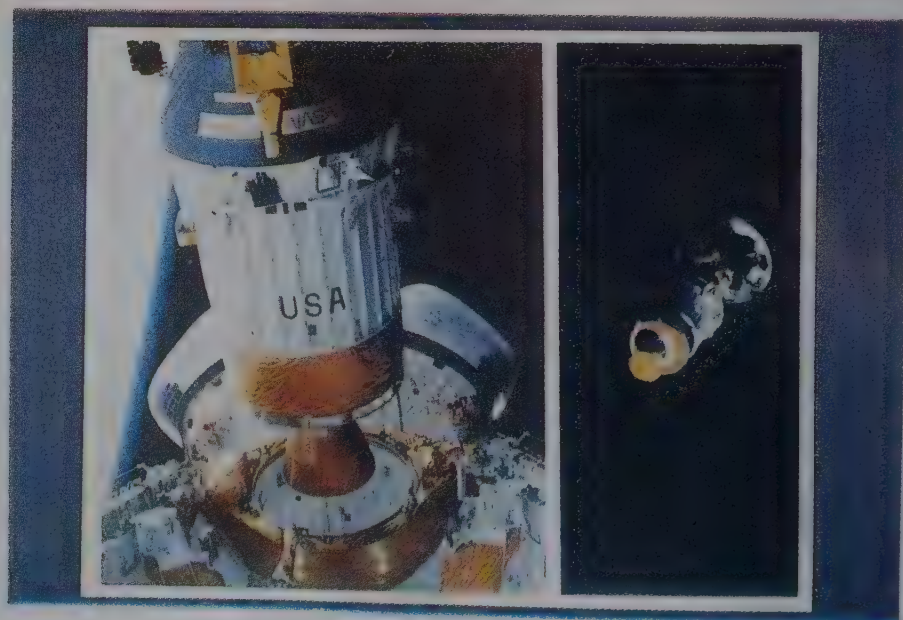


Plate XII The US spacecraft Galileo left the earth in October 1989 on a six-year journey to Jupiter. It is expected to orbit Jupiter in December 1995 and release a scientific probe into the planet's atmosphere (*Courtesy: USIS*).



Plate XIII The Orion (*Kalpurush*) nebula.



Plate XIV Another nebula—a birthplace of stars.



Plate XV The trifid nebula is also a birthplace of stars. It is 30 light years in diameter and 3,000 light years away (*Courtesy: Spectrum*).



Plate XVI The sun temple at Konark, Orissa.

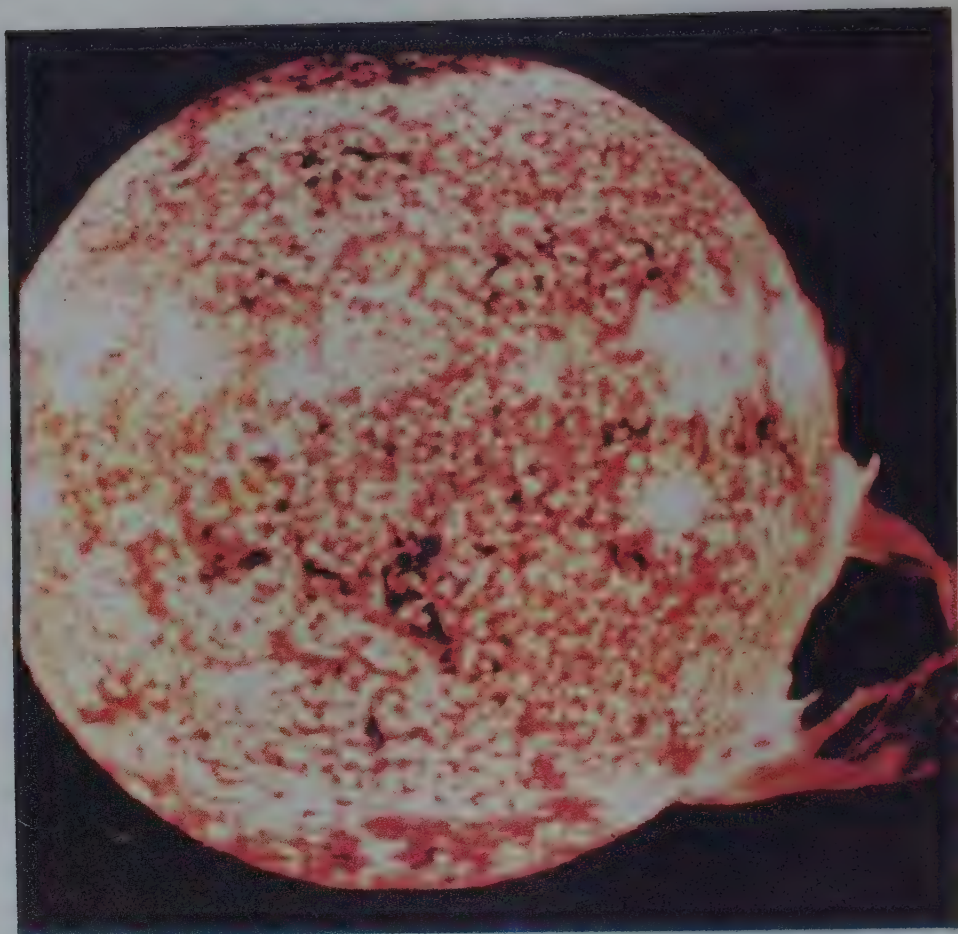


Plate XVII A view of the sun showing a long flame of gases (called a solar flare) coming out of it.

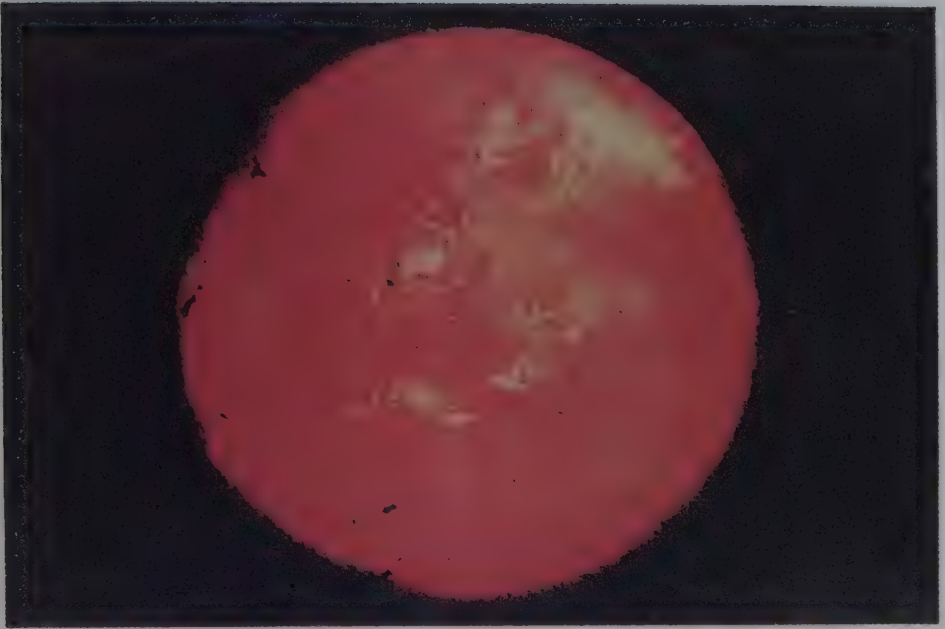


Plate XVIII Another view of the sun. The surface temperature of the sun is 5500°C , but the inside is much hotter.



Plate XIX The crab nebula.

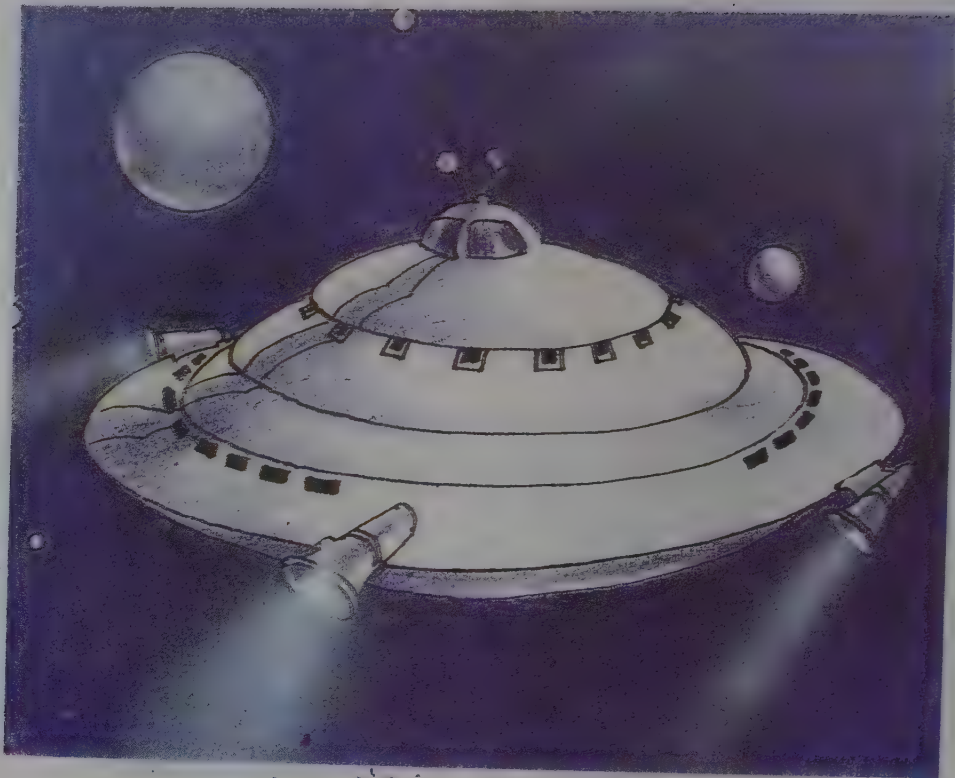


Plate XX An artist's concept of a flying saucer.



Plate XXI One of the two Voyager spacecraft launched by USA in 1987. Both the spacecraft have now left the solar system to enter the deep space (*Courtesy: USIS*).



Plate XXIII Will an alien look like any of these?

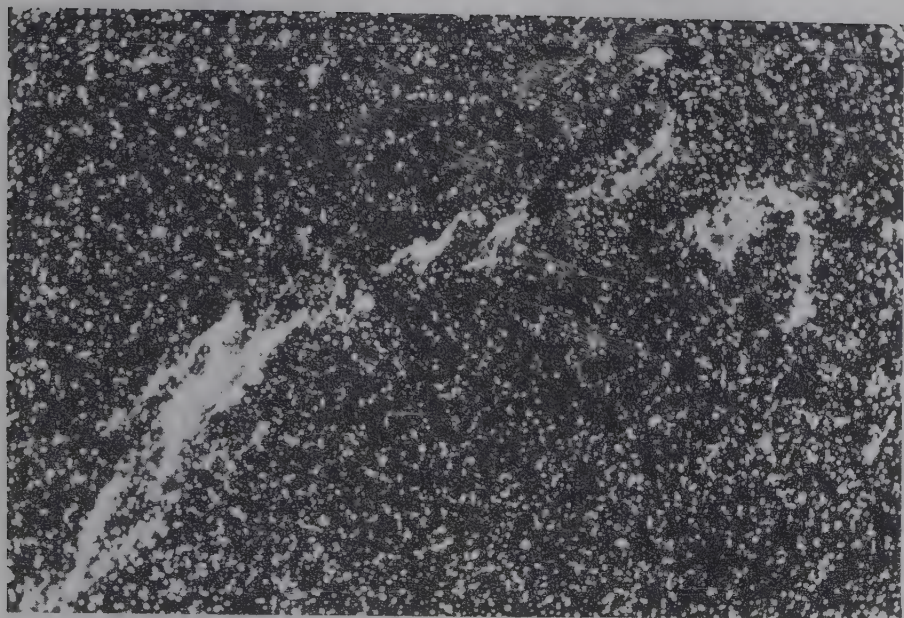


Plate A The sky at night.

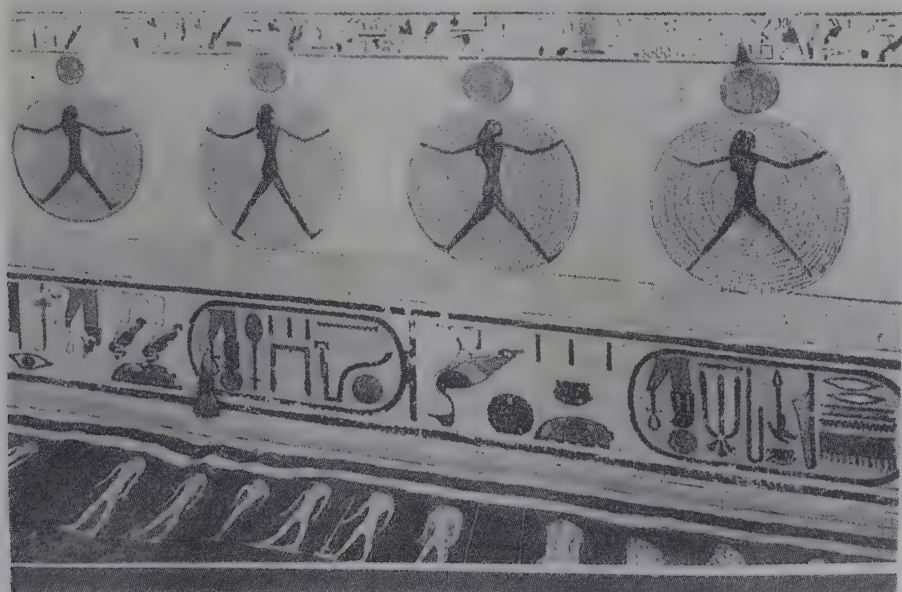


Plate B An ancient Egyptian painting in the tomb of Ramses depicts the study of the sun.



Plate C The observatory at Delhi built by Raja Sawai Jai Singh in the early 18th century.

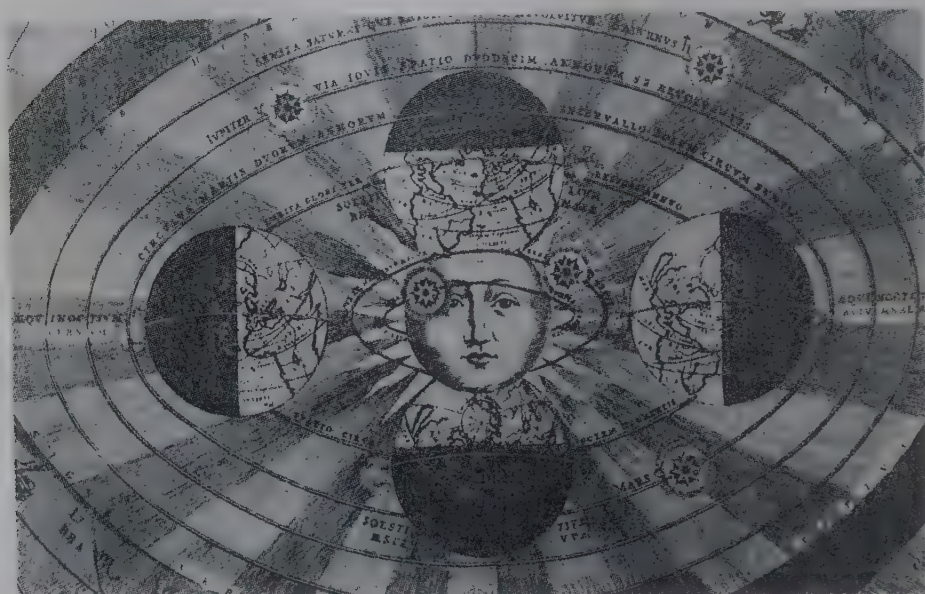


Plate D The Copernican Universe shows the earth as the centre of the Universe around which the moon and all the planets revolve.



Plate E Comet Bennett photographed in April 1970 from California
(*Courtesy: Smithsonian Institution, USA*).



Plate F Comet Halley photographed in 1919. This comet appeared again in 1985-86 (*Courtesy: Smithsonian Institution, USA*).

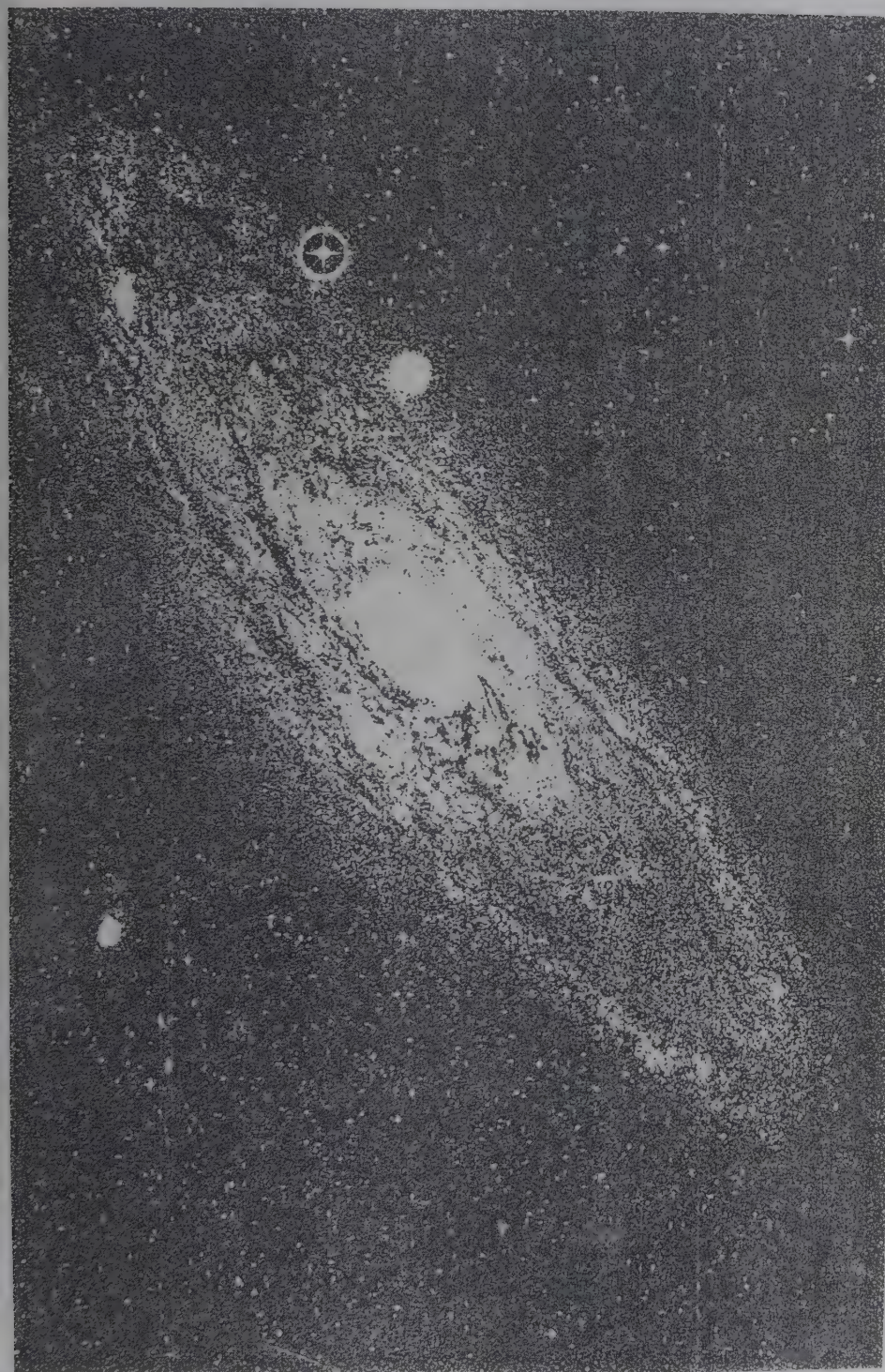


Plate G The Andromeda galaxy.

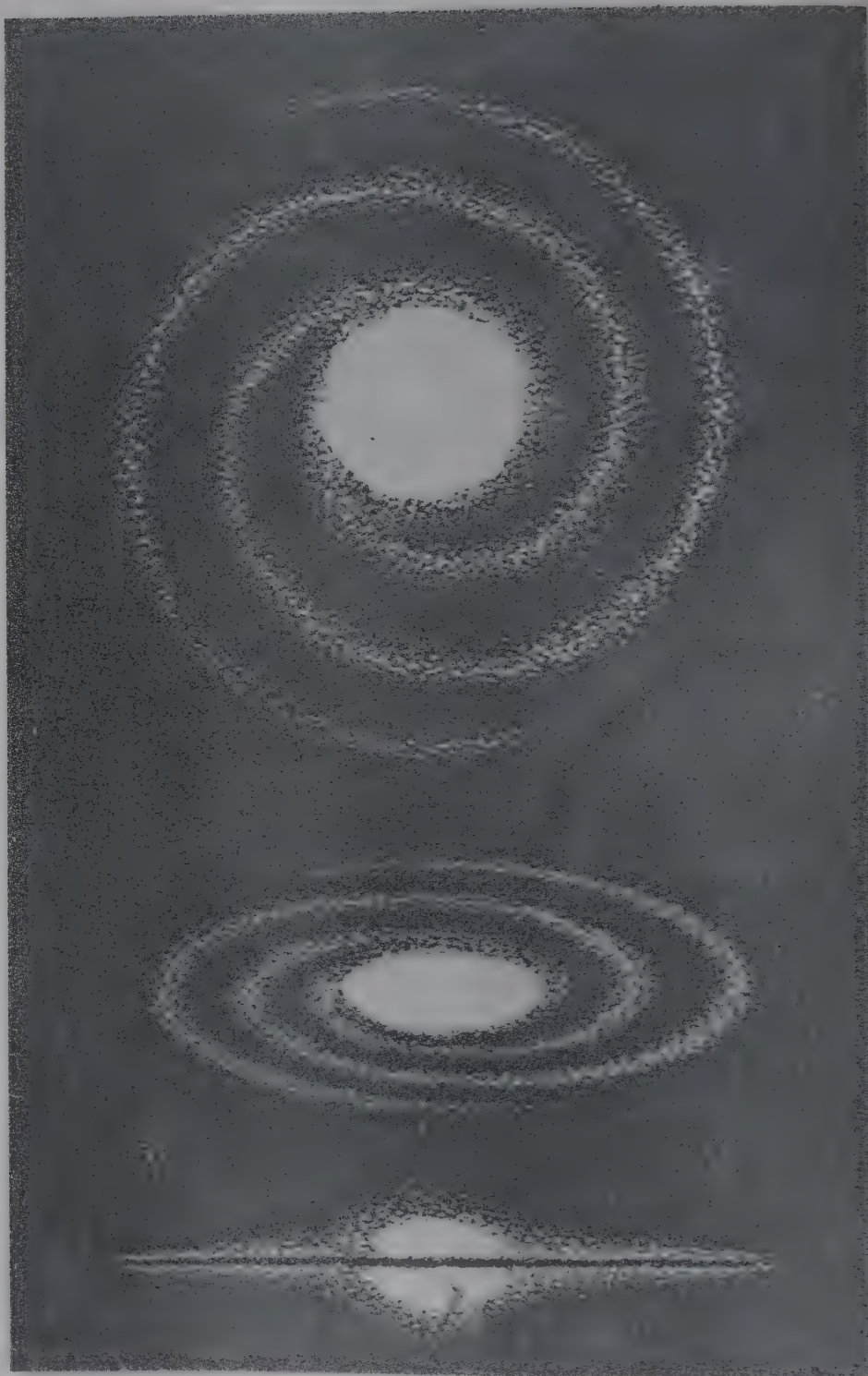


Plate H The flat galaxies in rotation.



Plate I The earth as seen from space.



Plate II A spectacular photograph of the earth and the moon taken by astronauts of Apollo 11 in July 1969. Courtesy of the NASA Archives. (Courtesy of the NASA Archives.)



Plate III The earth and the moon as seen in the photograph taken by the US spacecraft, Voyager I, on 18 September 1977 from a distance of 1,16,00,000 km (*Courtesy: USIS*).

The photograph below shows the rock fragments in the lunar surface.

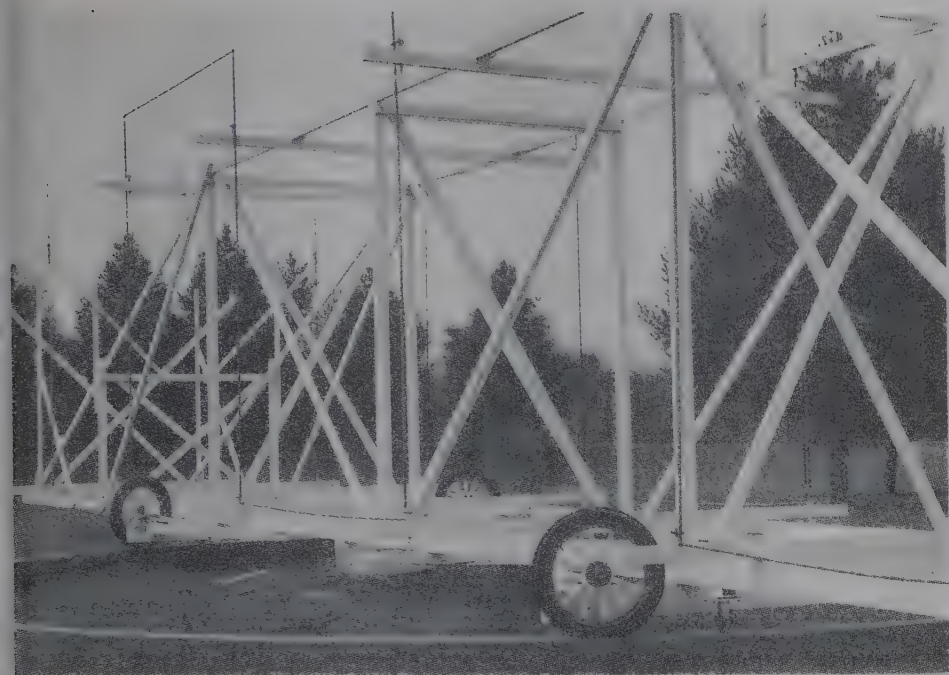


Plate I Full size model of Karl Jansky's first radio antenna
(*Courtesy: Smithsonian Institution, USA*).



Plate J The Supernova 1987 A.

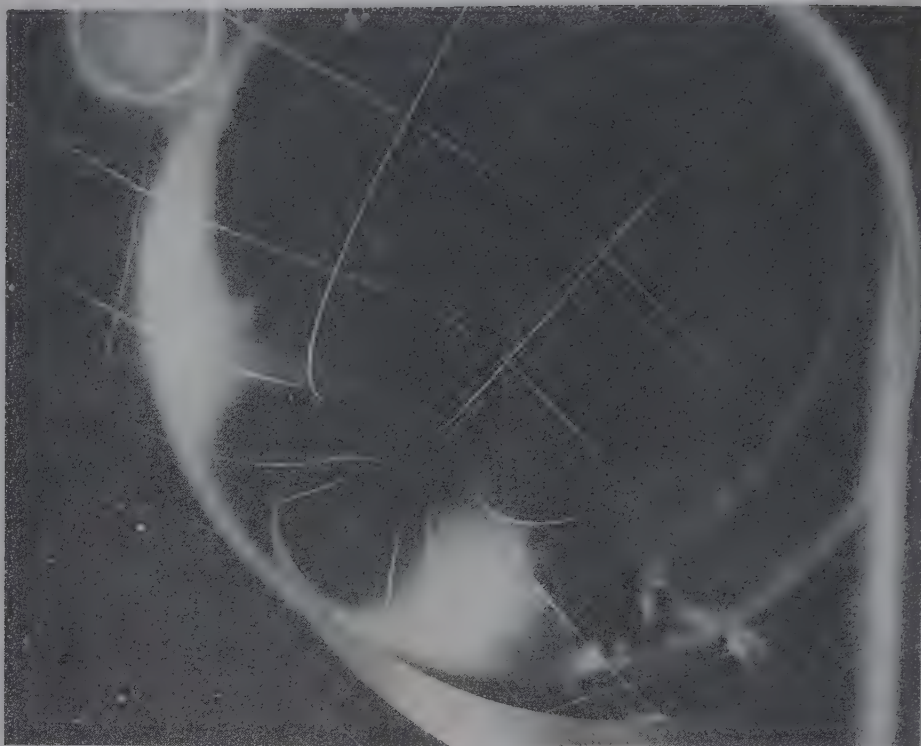
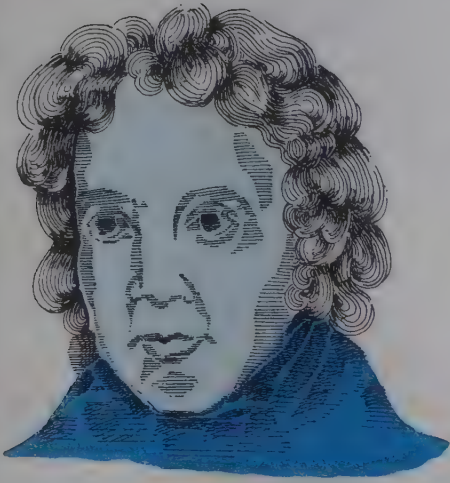


Plate K Artist's concept of a black hole.



Plate L Photograph of the great radio galaxy, Centaurus A. It is believed to contain an enormous black hole at the centre (*Courtesy: Spectrum*).



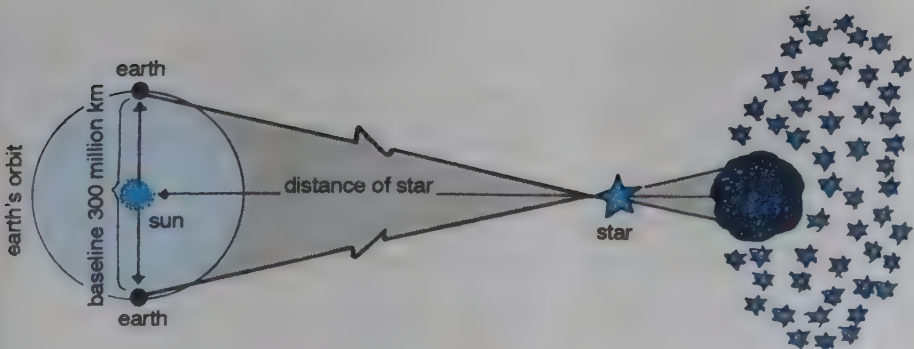
Friedrich Wilhelm Bessel.

km. This distance is 9,000 times the diameter of the solar system.

Cygni in the constellation of Cygnus (*Hamsamandal*). It was observed that the star changed position against the backdrop of the distant stars. Bessel recorded the various positions of 61 Cygni against the distant stars and after a full year's observation, in 1838 reported that 61 Cygni had a parallax of 0.31 second of arc. From a trigonometrical calculation the distance of 61 Cygni was found to be about 102 million, million

What is a Light Year?

Distance of millions and millions of kilometres are difficult to handle. Astronomers had been using the astronomical unit to express the distances in the solar system. But, this unit too proved inadequate for expressing the enormous distance of the stars.



Parallax of a star.

So the astronomers defined a new and bigger unit—the light year. One *light year* is the distance travelled by light in one year. Light travels 3,00,000 km in one second. In one year, light travels about 9,460,000,000,000 km or about 10 trillion km. This distance is called a light year. In terms of this unit, 61 Cygni is about 10.9 light years away from us.

Our Nearest Neighbour

Two months after Bessel's first successful measurement of the distance of a star, 61 Cygni (*Prathama Hamsa*), the English astronomer, Thomas Henderson (1798-1844), measured the distance of another star, Alpha Centauri (*Prathama Kinnara*). The star is visible from the Southern Hemisphere. It had a parallax of 0.75 second of arc, much more than that of 61 Cygni. Its distance from us was found to be 4.3 light years (about 40,678,000,000,000 km). It turned out later that Alpha Centauri was our nearest star neighbour and was actually not one star, but a cluster of three stars.

Friedrich Georg Wilhelm von Struve (1793-1864), a German-born Russian astronomer, measured the parallax of Vega (*Abhijit*), another bright star in the sky and found its distance to be 27 light years. Because of the large distance involved, the parallax was very small and, therefore, Struve could not measure it accurately.

By the year 1900 the distances of about 60 stars could be measured by the parallax method. With the instruments at the disposal of astronomers, parallax could be measured up to a distance of 100 light years. Stars in countless numbers were seen even beyond this limit. Man's Universe was growing.

By 1840 astronomy was in a very proud and healthy state. The solar system had been well charted, a large number of stars had been catalogued, the distances of a few stars had been measured and man's Universe had attained a bigger boundary.

The Camera and the Spectrometer

But the nature of the stars could not be understood. In 1835, the French philosopher, Auguste Comte (1798-1857), opined that science would never be able to reveal the constitution of the stars.

Comte was utterly wrong. Two devices—the camera and the spectrometer—made such breakthroughs in the realm of astronomy that soon the nature of stellar constitution became clear to the scientists.

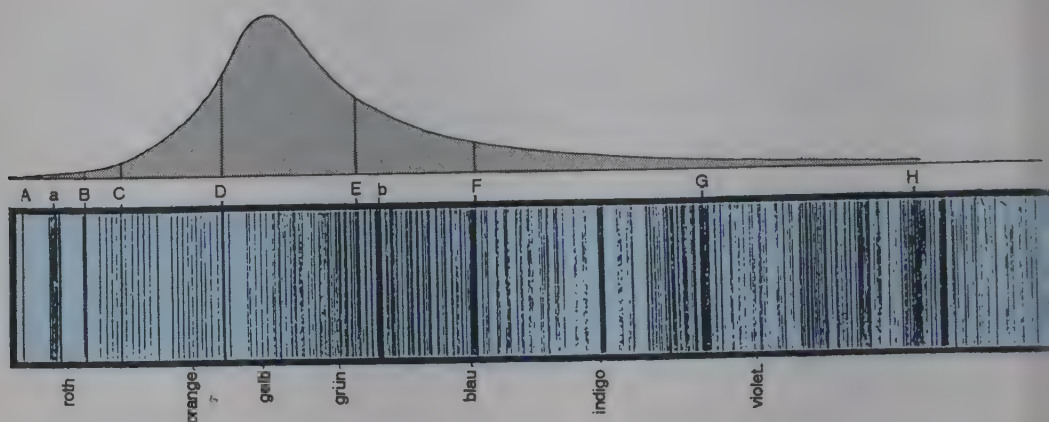
In 1839, photography became commercially successful and was soon applied to astronomy.

Now, at last, many objects could be permanently recorded. Till now objects in the sky had to be observed physically by the astronomers and only manual records could be kept. In 1840, John Draper of USA, succeeded in taking photographs of the moon. It took the astronomers ten more years to photograph the star Vega. By the end of the 19th century, however, astrophotography became relatively commonplace. Stars that were too faint to be visible to the naked eyes were also recorded by photographic devices attached to telescopes.

While perfecting a glass prism for precision measurements, Joseph von Fraunhofer (1787-1826), in Germany, observed that sunlight was broken into the beautiful colours of the rainbow when it passed through a prism. The pattern so obtained on the screen or on a film is called a *spectrum*.

Gustav R. Kirchhoff (1824-1887), a German physicist, collaborated with a chemist, Robert Bunsen (1811-1899), to devise a machine for breaking up light into spectra. In their spectrometer, light was passed through a narrow slit and then dispersed by a prism. Precise measurement of the composition of a star soon became possible with this method and the foundation for the use of the spectrum in astrophysics was laid.

A whole new branch of science called *spectroscopy*



Fraunhofer's analysis of the solar spectrum. The graph above shows the relative intensities of light of various colours.

developed and astronomers soon determined the constitutions of a number of stars. Comte was proved wrong.

Spectroscopy and photography developed so rapidly that by the beginning of the 20th century, astronomers were able to measure the composition, temperature, surface gravity, luminosity and velocity of a large number of stars.

The Milky Way and its Neighbours

The Milky Way is a strikingly beautiful sight in the night sky. It is too faint to be seen in bright moonlight or amid the myriad lights of large cities, but on moonless nights in the countryside one can make out the outlines of its cloudy track of light across the heavens. On seeing through the telescope, the Milky Way represents the combined light of a vast number of stars.

Ever since the introduction of the first telescope by Galileo Galilei, it was realised that with every improvement in the efficiency of the observing instruments, new realms of astronomy could be explored.

With the naked eye one can see about 6,000 stars in the clear sky. Since only one half of the sky is visible as the other half is obstructed from vision by the earth itself, we can see only about 3,000 stars. But, when Galileo trained his small telescope on the sky, he was surprised to see many more stars, previously invisible to the naked eye. A greater surprise was in store for Galileo. When he carefully directed his telescope at the Milky Way, he saw a large number of stars, which to the naked eye seemed like white, foggy patches of light.

The vague idea of the stars forming villages or kingdoms was propounded by the German-born English astronomer, William Herschel (1738-1822). Herschel, who discovered the planet Uranus and invented a new type of reflecting telescope, studied and catalogued about 5,000 nebulae and star clusters.

In 1785 Herschel said that the stars in the sky were



Sir William Herschel.

arranged in villages of the shape of a lens. He also said that the Milky Way was also a village of stars, that its central portion was actually very thick and that a large number of stars inhabited this village. The kingdom or village of stars called the *Milky Way* is also known as the *Galaxy*. The word 'galaxy' has been derived from the Greek word *milk*.

Herschel also deduced a formula to calculate the size of the Galaxy. He based his formula on the assumption that all stars were almost equally bright, and their brightness appeared to be different because of their various distances. This assumption was not correct. So his estimation on the size of the Galaxy—7,500 light years in diameter and 1,300 light years in thickness—was also not correct. Although his estimates were conservative, he had taken a step in the right direction.

Taking advantage of the newly developed technique of photographing stars, a Dutch astronomer, Jacobus Cornelius Kepteyn (1851-1922), made a fresh calculation about the size of the Galaxy. He proposed a diameter of 23,000 light years and a thickness of 6,000 years. But these too were far below the actual values.

Cepheids

The discovery of the peculiar oscillation pattern of a bright star called Delta Cephei presented the astronomers with a new measuring rod. The star was found to have a cycle in which its brightness increased from the dimmest to the brightest and then gradually waned again. This period was



The largest telescope used by Herschel. The tube was 12 m long and it had a mirror of 1.3 m diameter.

very regular. Soon the astronomers were able to locate quite a few of such *variable stars*. These stars were named as *Cepheid variables* or simply *Cepheids* after the first known of such stars—the Delta Cephei.

The Cepheid variables—stars that follow the oscillation patterns of Delta Cephei—have a pulsating period of a few days. Other pulsating stars have periods between a day and a couple of hours. The slowly pulsating stars are large and red, the faster ones smaller and blue. The period is related to the density of the star: the square of the period is inversely proportional to the density. The fastest pulsation known is that of a dense blue star that once became a nova. Its period is a little over a minute.

The variations of novas and Cepheid variables are not confined to their brightness. A study of their spectra shows that Cepheid variables, for example, change in temperature rhythmically as they vary. They are hottest when they are brightest, coolest when they are faintest.

The novas and the pulsating stars furnish measuring

sticks for the distant stellar systems. The absolute brightness of pulsating stars depends on their periods. Using such stars, astronomers have determined the distance of a great number of galaxies in which these stars occur.

An astronomer working at the Harvard University in USA, Miss Henrietta Swan Leavitt (1868-1921) discovered, almost accidentally, in 1912 that the actual brightness of the Cepheids depend on this periodicity. She established a graphical relationship called the *period-luminosity curve* from which, if the period of a Cepheid star is known, it is easy to find out its absolute luminosity or actual brightness.

The scale was a relative scale. If you know two Cepheids with equal periodicity, then you know that their actual brightness is also the same. But, suppose one of them, Cepheids A, is four times as bright as Cepheid B, then Cepheid B must be, according to a law governing brightness of light, twice as far as Cepheid A. If you could now determine the distance of one of them, the distance of the other could be calculated easily.

But the Cepheids were very distant stars. The nearest Cepheid, the Pole Star, was 300 light years away. It was, therefore, difficult to ascertain the distance of any one of them by the parallax method. However, applying a complex procedure, a Danish astronomer, Ejnar Hertzsprung (1873-1967), in 1913, determined the absolute magnitude of a Cepheid. He then fitted it to Miss Leavitt's curve. He could now determine the absolute magnitude of any Cepheid. The distances of the Cepheids could, therefore, be determined. An American astronomer, Harlow Shapley (1885-1972), also determined the distances of a few Cepheids by this method. Shapley also found a number of cluster of stars and from them tried to determine the size and shape of the Milky Way. Although his calculations were not very accurate, he was right in saying that globular clusters of stars surrounded the Milky

Way. He was also almost right when he said that our sun was not at the centre of the Milky Way but about 50,000 light years away from the centre. Based on a number of facts, scientists afterwards calculated that the sun was about 30,000 light years away from the centre of the Galaxy. The sun with its family travels round the galactic centre at a speed of about 240 km per second. It completes one rotation about the centre of the Galaxy in about 200 million years.

From the speed of rotation of the Galaxy, the gravitational field of the galactic centre was calculated; from which its mass was calculated. The mass was found to be over 100 billion times the mass of our sun. Since our sun is a star of an average mass only, our Galaxy must contain about 200 billion stars (2×10^{11} stars). The diameter of our Galaxy was also determined to be 1,00,000 light years, and its thickness was determined to be 20,000 light years.

In the meantime, with the help of the Cepheids, the distances of the Large and the Small Magellanic Clouds were determined. They were found to be more than 1,00,000 light years away. It is now known that the Large Magellanic Cloud with about five billion stars is about 1,50,000 light years away and the Small Magellanic Cloud with 1.5 billion stars is about 1,70,000 light years away.

In the 1920s, therefore, the known Universe was less than 2,00,000 light years in diameter and it consisted of our Galaxy and its two neighbours, the Large and the Small Magellanic Clouds. Astronomers, of course, never stopped asking themselves, "Is there anything outside this limit?"

Astronomers had been noticing since a long time some foggy clouds in the sky at very large distances. Many of these were visible to the naked eye. These are called *nebulae* after the Greek word for 'cloud'. A French astronomer, Charles Messier (1730-1817), had catalogued a number of them in about the year 1782. One spectacular nebula is the nebula referred to as M 31 by Messier. It is known as the Andromeda nebula, because it is in the constellation Andromeda (*Rewati*).

Andromeda Galaxy

In 1924, the great American astronomer, Edwin Powell Hubble (1889-1953), directed his new 254-cm telescope at Mount Wilson in California on the Andromeda nebula. He found the nebula was not a patch of cloud only, it was filled with stars. Hubble decided that the Andromeda nebula was a galaxy or a kingdom of stars like our own Galaxy, the Milky Way.

With the help of the Cepheids present in the Andromeda, and with the application of the Leavitt curve, the distance of the Andromeda galaxy was found to be about a million light years.

After Andromeda, a large number of nebulas were studied by improved models of telescopes and they were all found to be galaxies of various shapes and sizes, made up of millions of individual stars. Many of these galaxies were found to be spiral shaped. Later on, our own Galaxy, the Milky Way, was also found to be of the spiral type. They have curved arms which make them look like octopuses.

There are other types of galaxies also. Some are elliptical, others are spirals crossed by a broad band formed by stars. As the telescopes became more and more powerful, more and more galaxies were discovered. Astronomers now estimate that there might be ten thousand million (10^{10}) galaxies in the Universe. The realm of the Universe expanded still further—it is perhaps several hundred million light years across.

One puzzle kept on disturbing the astronomers. All the galaxies were found to be smaller than our Milky Way Galaxy. But, the German-born American astronomer, Walter Baade, solved this puzzle after he was able to use the more powerful 500-cm Hale telescope at Mount Palomar in California. He found that the Leavitt curve did not apply uniformly to the two classes of Cepheids discovered till then. He had, therefore, to revise the

period-luminosity curve and the distances and the dimensions of the galaxies.

Many of the galaxies were now found to be the size of the Milky Way and their distances also almost doubled. The Andromeda galaxy was found to be more than two million light years away from us. The size of the known Universe also doubled.

But, this was not all. Astronomers now believe that just as the stars form clusters and many of the star clusters together form galaxies, so also galaxies form a cluster of galaxies. These may be called *supergalaxies*. Supergalaxies may, in their turn, form *super-supergalaxies*. And, could there be super-super-supergalaxies and super-super-super-supergalaxies? No one knows for sure!

The most powerful modern telescopes have shown that clusters of galaxies actually exist. In the constellation of Coma Berenices, there is a large, ellipsoidal cluster of galaxies which consist of about 11,000 individual galaxies. This cluster, known as the *Coma cluster*, has a diameter of eight million light years. The average distance of the individual galaxies in this cluster is only 3,00,000 light years. But, the average distance between our neighbouring galaxies is three million light years.

Our galaxy may be a member of a local cluster, the other members being the Magellanic Clouds, the Andromeda galaxy and a few other small galaxies. This local cluster may be the part of a bigger cluster.

Many astronomers are today convinced that galaxies form supergalaxies while supergalaxies, in turn, form still bigger clusters, the super-supergalaxies. If this is so, the Universe with the clusters and clusters of clusters must go on and on without a limit in space. Some argue that there is no end of space. Others argue that space also has its limit—its boundary. No one knows which view is correct. But as the probing instruments are becoming more and more powerful, the depth of the space seems to be ever increasing.

The Ever Expanding Universe

The American astronomer, Vesto Melvin Slipher (1875-1969), had been studying spectra of the stars and the galaxies with a spectrometer. When you pass the light from a star or galaxy through a spectroscope or a spectrometer, you get a spectrum. That means that the light is broken up into its constituent colours. The positions of certain dark lines in such a spectrum are known to the scientists. If the source of light is approaching us, we get a shift of these dark lines of the spectrum towards the blue end. If it is going away, we get a shift towards the red end of the spectrum.

The explanation for this is found in a theory given by the Austrian physicist, Christian Doppler (1803-1853), in 1842. When a whistling railway train approaches us, the frequency of the whistle or the pitch of the whistle increases. When the train moves away, the frequency of the whistle or the pitch decreases. The same effect takes place when a source of light approaches us or recedes from us. If it approaches, the frequency of the light increases and the light that we see shifts towards the high-frequency end, i.e. the blue end of the spectrum. When the source goes away from us, the light shifts towards the low-frequency end, i.e. red end of the spectrum. The shift is proportional to the speed with which the source is moving.

With the help of the red and blue shifts in the spectrum, Slipher started measuring the speeds of the galaxies. In 1912, he found that the Andromeda galaxy was moving towards us at about 200 km per second. His

interest in the measurement of speeds of the galaxies, therefore, grew. By the year 1914, Slipher completed measuring the speeds of 15 galaxies. He found 13 of them going away from us.

As the movement of more and more galaxies were observed by scientists, it was found that almost all the galaxies, excepting a few nearby galaxies, moved away from us. With the improvement in detecting techniques, more distant galaxies could be observed. In 1929, the American astronomer, Edwin Hubble, found that the more distant a galaxy was, the more was the red shift. This meant that the further a galaxy was from us, the faster it was fleeing away from us.



A balloon when inflated shows spots moving away from one another.

The Universe, therefore, appears to be expanding. In order to understand this you may consider a balloon with a number of spots on it. As you inflate the balloon, the spots will move apart. Imagine now an ant sitting in one of the spots and try to visualise what the ant would see. To the ant sitting in a particular spot, all the other spots will appear to be receding. Moreover, the more distant a spot is, the faster it will appear to recede from the ant. Even if you make the ant sit in any other spot, the scene will not change. It will not matter on which particular spot it is sitting.

The galaxies in the expanding Universe also behave like the spots in a balloon that is being inflated.

Hubble and subsequent workers measured the speeds of a number of galaxies with gradually better and better equipment. A cluster of galaxies in the constellation of Virgo (*Kanya*) which is about 50 million light years from us was found to be moving away from us at a velocity of 1,200 km per second. A group of galaxies, 2,700 million light years away, in the constellation of Hydra (*Vasuki* or *Hradasarpa*), was found to be receding at 57,600 km per second.

Isaac Asimov (1920-1992), the world's all time prolific science writer from America, raised a tricky question here. If, according to Hubble, the galaxies flee away faster and faster as they are more and more distant from us, i.e. if the speeds of the galaxies increase with distance, there will be a particular distance at which the galaxies will fly away at the speed of light. Beyond the boundary, a galaxy will move away at a speed greater than the speed of light. Then, light from that galaxy will not reach us. We shall, therefore, not see such a galaxy. In other words, nothing in the Universe beyond this limit will be visible to us. Asimov has calculated that this limiting distance is 12.5 billion (12.5×10^9) light years. Asimov, therefore, concludes that the observable Universe has a diameter of 25 billion light years and the number of galaxies it contains is uncertain.

The Big Bang

Many astronomers now believe that at the beginning there was a superheavy, superdense 'cosmic egg' which exploded and gave birth to the ever expanding Universe. The galaxies and nebulae that we see today were formed from the matter that was scattered in that cosmic explosion which they call the *big bang*. This *big bang theory* was proposed in 1927 by the Belgian astronomer and cosmologist, Abbe Georges Edouard Lemaitre (1894-1966). We see the galaxies and nebulae today in the process of fleeing away from that central point where the big bang took place.

By reversing the time-scale of this expansion, scientists have calculated that such an explosion occurred more than 15,000 million (15 billion) years ago. At that time the density of that original 'egg' before the explosion must have been such that every cubic centimetre of it contained a hundred million tonnes of matter. It was the beginning of everything when space, matter, radiation and time were born.

It is always seen that when matter is compressed it gets heated up. The original Universe, when it was highly compressed as a nucleus, must have been very hot. Because of this high temperature, the egg or the nucleus must have exploded at some point and expansion of the Universe began. It is this expansion that has been continuing. All the chemical elements that we know were created within the first 30 minutes of the big bang.

Astronomers have found evidence that such a big bang did actually occur. For such an explosion to occur, the compressed Universe must have been very hot and filled with radiation. As the Universe expanded more and more, it must have gradually cooled down. Scientists have calculated the original temperature of that 'cosmic egg'. From calculations they have found that the temperature of the background radiation should now fall to about three

degrees above absolute zero. Absolute zero means zero degree Kelvin or -273° Celsius.

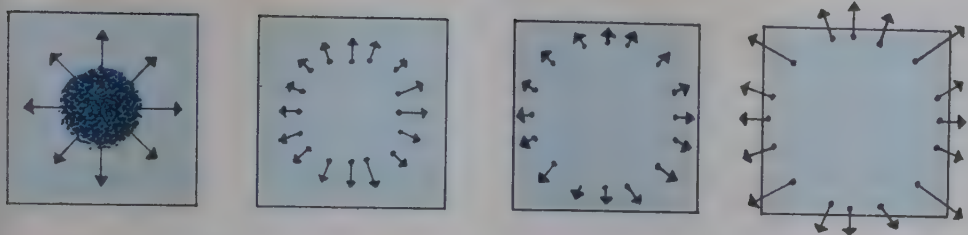
In 1965, radio astronomers have found that all space has this temperature. Astronomers feel that this has proved that the Universe is expanding after explosion of the cosmic egg.

According to the Russian-born American physicist, George Gamow (1904-1968), for 250 million years after the explosion, radiation was much more in the Universe and matter was much less. Gradually matter formed out of the radiation. The matter, therefore, remained everywhere in the Universe as thin gas. Gradually, matter became more predominant than radiation. Out of the thin gas, by condensation, stars and galaxies formed. But this process of formation of stars and galaxies has not halted the expansion. The galaxies are flying away at tremendous speeds as fragments of any explosion fly away. Gamow believes that because the Universe is expanding and the other galaxies are receding from us, all other galaxies will go far, far away from us. We will then be almost alone in the Universe; our Milky Way Galaxy will have only a few local galaxies nearby.

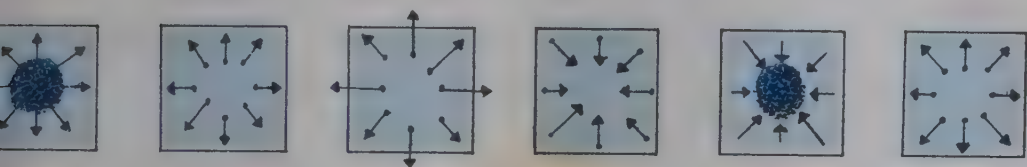
Pulsating Universe: A Big Crunch

Astronomers who believe the big bang theory, are almost sure about how the Universe began. But they are quite unsure about how it will end. Some think that it will continue to expand for ever. Their *Universe* is called *open universe*. Others think that the expansion of the Universe will one day stop and the reverse process, i.e. contraction will start. Because of the contraction, the Universe will gradually become smaller and smaller and at one point of time, contract into the original cosmic egg. In contrast to the big bang this event is called a *big crunch*. This Universe is a *closed universe*.

The American astronomer, Allan Rex Sandage (1926-),



A great explosion (*big bang*) in a dense cosmic egg started the process of expansion of the egg which is still continuing.



Some think that the Universe follows a cycle of expansion and contraction. A big explosion occurs in the cosmic egg and the Universe expands. Then expansion stops and then again a big bang takes place. The process continues endlessly.

suggested that the Universe expands and contracts alternately as described above. The period for such an oscillation—expansion and contraction—runs into several tens of billion years. Sandage thinks that a great explosion took place some 12 billion years ago and the Universe has been expanding since then. It will continue to expand for 29 billion years more when gravitation will halt further expansion. A contraction process will then start. That will continue for 41 billion years. At the end of that period, the Universe will condense into a superdense cosmic egg and again the explosion will take place. Other astronomers who believe in a pulsating Universe set the time of the great explosion 15 billion years back.

Steady State Theory

In 1948, an altogether different theory of the Universe was

proposed by two British astronomers, Hermann Bondi (1919-) and Thomas Gold (1920-). Another British astrophysicist, Fred Hoyle (1915-), and an Indian astrophysicist, Jayant Vishnu Narlikar (1938-), strongly supported and popularised this idea. Their theory is called the *steady-state theory*. According to them the Universe did not change and will not change in time. They agree that the galaxies are moving away as the Universe continues to expand.

We have come to know that the farther a galaxy is from us, the faster it is in receding from us. So, the farthest of the galaxies will at one point reach the speed of light. From then onwards, no light from that galaxy will reach us. That galaxy, therefore, will be lost from our visible Universe.

But according to the theory, as galaxies leave our Universe, new galaxies are continuously forming in the vacant space among the old galaxies. These new galaxies form from the new matter which is continuously being created out of the energy in the Universe. The theory is, therefore, known as the *continuous creation theory* also.

But, galaxies with their millions of stars are very massive. Therefore, for every galaxy that leaves our Universe, huge amounts of mass will have to be created in the void. George Gamow has calculated the amount of matter that will have to be created to compensate for the lost galaxies. He found that if one hydrogen atom is created in every litre (1,000 cubic centimetres) of space even in a billion years also, the loss will be compensated.

As the lost galaxies will be replaced by new galaxies, the Universe will not change in time. For an observer at any point of the vast space, the galaxies will always appear to be receding. But, he will never be alone, because new neighbours will join him.

New Windows to the Universe

When undersea telephone cables were laid, telephone users and communication engineers were perplexed at the presence of some background noise during the telephone calls. To solve the mystery, Karl Jansky (1905-1950), a US telephone engineer, built a robust 29-m radio antenna. It was built on a circular track to allow it to be moved around freely to face any direction. After long and painstaking experimentations, Jansky discovered in 1933 that the source of the static noise was the centre of our Milky Way Galaxy.

Jansky accidentally created the world's first radio telescope and launched the field of radio astronomy. Radio telescopes today allow scientists to 'see' objects billions of light years away, detect energy left over from the big bang—the giant explosion that formed the Universe some 15 billion years ago—and even search for extraterrestrial life forms.

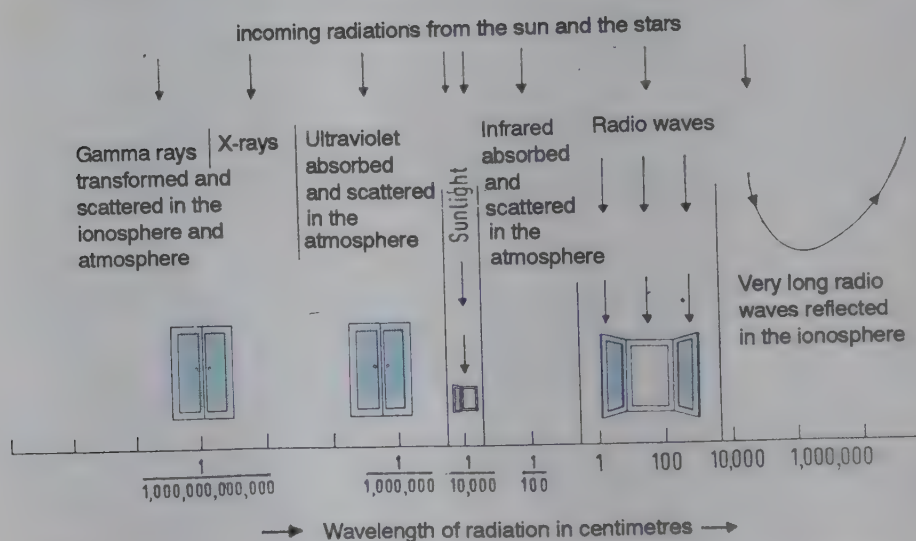
With the help of radio telescopes, astronomers today explore such heavenly objects as quasars, exploding supernovas and black holes, as well as *binary stars* (which are systems of a pair of stars). Many galaxies which are not visible through the optical telescopes are also 'seen' through the radio telescopes. Radio signals from these galaxies confirm that they are fleeing away from our Milky Way. This proves that the Universe is expanding.

The Universe is, therefore, not as quiet as it seems to be from the earth. Constant murmurs are going on everywhere in the Universe. Today, a combination of

several radio telescopes is used to focus on very distant objects in space. For example, in the New Mexico desert, a set of 27 movable antennas is distributed in a Y-shaped formation covering 32 km. This is called the *very large array*. The 'viewing' power of such a system is very high.

In 1986, astronomers created a temporary radio telescope nearly one-and-a-half times the size of the earth's diameter. This was done by correlating signals from two ground telescopes and from the Tracking and Data Relay Satellite in space. The resulting image of certain very distant objects, including a quasar, were much clearer than the earlier images. In 1990, a 240-cm Hubble Space Telescope was placed in orbit by NASA. Its position above all atmospheric interference has allowed the space telescope to probe seven times deeper into the cosmos than the strongest ground-based telescope.

Radio telescopes have also detected complex organic molecules throughout the Universe. This has opened up the possibility that life may exist elsewhere in the Universe.



An artist's concept of the electromagnetic windows of Universe where only a small window in the visible light portion and a slightly bigger window in the radio wave portion are 'open' to us.

The rest is closed because of the presence of the atmosphere.

Other Windows to the Universe

Using Jansky's technique, Grote Reber (1911-), a US electrical engineer, built his own dish-type radio antenna in 1938. With this telescope Reber picked up strong radio signals from the Cygnus A galaxy. This galaxy is located far away from the centre of our Galaxy.

Astronomers who were habituated to the optical instruments—the telescope, the camera and the spectrometer—were not ready at first to accept a new tool like a radio telescope. But gradually the enthusiasm built up.

Two other Bell Laboratory employees first discovered physical evidence of the ultimate cosmic event—the big bang. In 1965, physicists Arno (Allan) Penzias (1935-) and Robert Woodrow Wilson (1936-) were investigating the cause of noise in their radio receiver. They learnt that the instrument was picking up the background radiation that exists everywhere in the Universe as remnant of the big bang. For their discovery, Penzias and Wilson won the Nobel Prize in physics in 1978.

With the launching of artificial satellites, major changes took place in the area of astronomy also. The early astronomical observations were ground based. The atmosphere with its dust, cloud and air molecules hindered the observations. The launching of satellites made it possible to study the heavenly bodies and phenomena from outside the atmosphere. Till quite recently only the very narrow visible part and the slightly bigger radio wave part of the electromagnetic spectrum were the only windows through which information about the Universe could be collected. The earth's atmosphere obstructed the view of other portions of the electromagnetic spectrum from us. With the launching of artificial satellites, many new windows of the electromagnetic spectra—X-rays, ultraviolet rays, gamma rays and infrared rays—were opened.

These specialised branches of astronomy have developed in leaps and bounds during the last two decades.

The Life of a Star

As the telescope gradually became more and more powerful, more and more stars which were earlier invisible to the naked eye became visible. But the thousands of millions of stars in the heavens are very far away from us. They, therefore, appear to us as points of light. Only our own star, the sun, shows a disk. So, all studies about the stars were at first concentrated on our sun only. We, therefore, know more about our sun than about any other star.

Our sun is a big ball of glowing gases. It is mostly hydrogen gas. As the radiation coming out of the big bang transformed into matter, thin lumps or clouds of gas, mostly hydrogen, formed everywhere. Some of this gas got concentrated at some regions of space and large patches of clouds called the *nebulas* formed.

It is from such clouds that stars were born. Some of the materials in the *nebulas* began to get accumulated to form lumps. Nearby materials got attracted. After a while, enough mass was formed in the dense region of the *protostar*, to generate heat by gravitational concentration. Then the central region eventually became sufficiently hot and dense. The hydrogen inside transformed, in a nuclear reaction, into helium and, in the process, released enormous amounts of energy. The star then began to shine.

The original gas material continued to revolve round the star. It probably formed a disk as it contracted. This disk gathered into small bodies which then accumulated to form solid bodies called *planets*. These planets began to

circle the star in the same direction and in the same plane.

Our detecting instruments have not yet been able to detect planetary systems around any other star, excepting our sun. Astronomers, however, have indirect evidences that many stars have planets.

Our Own Star: the Sun

The sun is the centre around which the earth and the other planets of the solar system ('solar' means 'relating to the sun') revolve. Many ancient peoples in the world worshipped the sun, made offerings and built temples, examples of which can be seen even in our own country at Konark in Orissa or at Modhera in Gujarat. For the most part their life depended upon agriculture, and they associated the sun's warmth with the crop-growing season.

Although the ancient sun-worshippers knew much less than we do know about the sun, they were aware of its life-giving importance. Our sun provides the crucial heat and light necessary to sustain life on the earth.

The sun is a star, rather an ordinary one, in fact. Our sun is only of average size when compared to other stars which are bigger, heavier, hotter and brighter. The sun appears brighter and bigger because it is much more closer to us than any other star is.

Our sun has a diameter of about 14,00,000 km—more than 100 times that of our earth. Its mass is 3,33,420 times the earth's mass. It also gets energy from nuclear reactions taking place inside it. The temperature of its surface is 5500° Celsius and it gives out a yellowish white light. The temperature of the sun's centre may be 14000000° Celsius.

The sun is only an ordinary star, of a type known as *yellow dwarf*. There are many hotter stars, and many cooler stars in the sky. A star named Spica (*Chitra*), for example, has a surface temperature of 20000° C. It shines a brilliant blue-white. There are many bigger stars and many smaller stars also as compared to the sun. The red giant

star, Aldebaran (*Rohini*), is tens of times bigger than the sun. There are also supergiants such as the Betelgeuse (*Ardra*), which is about 350 times the diameter of our sun. Another red giant, Mira, is about 450 times the sun's diameter.

Astronomers cannot follow any particular star through its life history because a star's life spans thousands of millions of years. But they can observe different stars at different stages of life and then can prepare a general life history of stars.

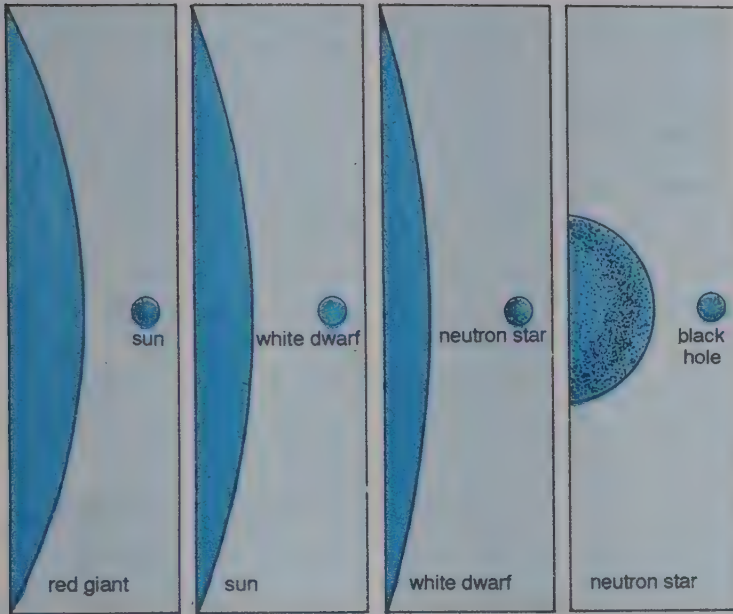
Giants and Dwarfs

When a star is about ten billion years old, the hydrogen inside it gets depleted. At that time the star's outer region swells up and reddens. The star becomes much bigger than its original size. Such stars are called *red giants*. Our sun, which is about five billion years old, is expected to become such a red giant five billion years from now.

As they age, the red giant stars become smaller and smaller. Sometimes they *pulsate* also, that is, they become alternately bigger and smaller. They also alternately become brighter and dimmer. They are then called *variable stars*. Then a stage comes when the star stops becoming bigger any more. They only shrink in size and shed off some of the outer gas layer. Only the core remains. The core is only about 10,000 km in diameter.

There comes a time when all the materials inside the star that can produce nuclear reactions are used up. They cannot produce any heat or light, but still may shine for a billion years before they cool down. At this stage they are called *white dwarfs*.

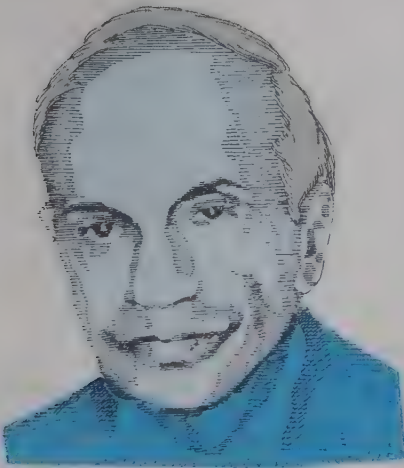
If the mass of the star is comparable to or smaller than that of the sun, the star will gradually shrink in size and grow fainter and denser. It will also become a white dwarf and will glow white. Then there will come a time when it will stop glowing. This will be the death of the star.



A comparison of the sizes of a red giant, our sun, a white dwarf, a neutron star and a black hole.

The noted Indian-born American astrophysicist, Subrahmanyan Chandrasekhar (1910–), carried out detailed mathematical calculations about the inner

structures of the stars. A nephew of the Indian Nobel laureate, Sir Chandrasekhara Venkata Raman, Chandrasekhar gave a mathematical relation about the behaviour of the stars of various masses. He determined a particular factor known as *Chandrasekhar's Limit*—it is 1.44. In 1930, Chandrasekhar found that a star having a mass more than 1.44 times the mass of our sun does not



Subrahmanyan Chandrasekhar.

form a white dwarf. Such a star continues to shrink. The star then blows off gases from its body by a *supernova explosion* and then it becomes a *neutron star*. A star, which is much more massive, continues to shrink till it becomes a *black hole*. Scientists could understand supernovas, the neutron stars and the black holes from these calculations only.

Novas

Before becoming white dwarfs, some stars may glow ten to 20 times more than their normal glow and then gradually fade. Such stars are called *novas*. The unusual brightness may be due to an explosion at the surface of the star. The brightness of a nova of which the astronomers have a definite record appeared in the constellation of Cassiopeia in November 1572. It was observed by Tycho Brahe. It was so bright that it could be seen during daytime also. It gradually disappeared from view in about 15 months. Another particularly brilliant nova was observed by the German astronomer, Johannes Kepler in 1604. It remained visible to the naked eye for 18 months and was called *Kepler's star*.

Supernovas

In a supernova explosion, the whole structure of the star goes into immense brightness. Such a supernova explosion may occur in our Galaxy once in a few hundred years. It is recorded in Chinese chronicles that the supernova explosion of 1054 outshone the sun for many days and turned nights into days. Astronomers think that the Crab Nebula is the remnant of that supernova.

On 24 February 1987, a young Canadian astronomer, Ian Shelton, working at the Las Campanas Observatory in Chile, noticed a bright spot in a photograph he had taken of the region near the Large Magellanic Cloud. He could



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Soon understand that a star had exploded there in the Tarantula Nebula. Other astronomers also confirmed it as a supernova and it was named Supernova 1987 A. It became 25 crore times as bright as the sun.

Signals from this event travelled for 1,70,000 years before they reached our planet, because the supernova was 1,70,000 light years away from us. As the supernova was comparatively nearer to us, astronomers could study its spectrum in detail. They understood that a massive star had exploded.

Pulsars

The discovery of pulsars in 1967 was one of those lucky accidents that happen in scientific research.

Some supernovas may, after the explosion, leave a supernova core which rotates at high speed. Eventually these remnants may transform into pulsars. A *pulsar* means a pulsating radio source. These strange objects send out a stream of radio pulses, X-rays and gamma rays like the ticking of clocks, every second or so with great regularity.

Pulsars are believed to be very small stars, only a few kilometres in diameter. They consist mainly of subatomic particles called *neutrons*. For this reason, pulsars are sometimes called *neutron stars* also. Such neutron stars are very dense. They contain the mass of several suns in a ball of diameter 30 km or so.

Quasars

There are other kinds of stars known as the *quasars* or the *quasi steller radio sources*. They may be extremely distant from us—more than a billion light years away. But they are very, very bright stars which emit radio waves in pulses. Research by some astronomers indicates that the brightness of a quasar decreases as its red shift increases.

Some quasars, which are a million times smaller than the galaxies, shine with the brilliance of hundreds of galaxies.

Because of their distance, astronomers have not been able to discover their secrets fully.

Black Holes

Astronomers have some indirect evidence of some very interesting bodies in the sky. For example, they have found evidence that near a bright star in the constellation Cygnus, there is an invisible companion to the star. It is six times as massive as the sun. But, it is so compressed that it is only a few kilometres across.

Such bodies, or stars, are called *black holes*. It is such a massive body and has such a strong force of gravity that nothing, not even light, can escape from it. Thus, a black hole does not shine or reflect light. The greatest cosmologist of our time, Stephen W. Hawking (1942) of UK, has recently opined that these mini-holes also emit some radiation. These black-hole emissions have now been named *Hawking radiations*.

Astronomers think that stars which are ten times or more bigger than the sun may explode as supernovas towards the end of their life. The core of the matter left after the explosion will collapse and shrink. If the mass is only up to two to three times the mass of the sun, the core will then form a neutron star. But, if the core is much heavier, it will be compressed beyond the neutron stage. Its gravity will go on increasing. A stage will then be reached when nothing can escape out of it. It will then be called a *black hole*.

Life on the Other Worlds

Since time immemorial man has been believing that other life forms exist in the Universe. In the olden days, people believed that the sky was full of more intelligent life and gods and goddesses kept watch on us and controlled our activities.

More than 2,500 years ago, the ancient Greek philosopher, Metrodorus, wrote: "To consider the earth as the only world with life in all space is as absurd as to believe that in an entire field sown with grain, only one plant will grow."

In modern age also many speculations about this have been made by the science-fiction writers. The noted English writer, H.G.Wells, has described a Martian (a being from Mars) in his novel *The War of the Worlds*, published in 1898. He has related how the Martian invaders of the earth, octopus-like monsters with intelligence far beyond man's, nearly destroyed human civilisation. Wells' story, though fanciful, reflects the thinking of many about possible life on other planets. But, recently the subject has moved out of the realm of science fiction. A rigorous scientific search is now going on for life, and particularly, intelligent life outside the earth.

Astronomers have found evidence of complex organic molecules almost everywhere in the Universe. They feel it is illogical to think that only our earth can sustain life forms when possibility of life exists elsewhere in space.

In our own Galaxy, the Milky Way, there are 200,000,000,000 (20 thousand crore) stars. Although it has

not been possible to detect any planet near any of the other stars, indirect evidences are getting stronger that many of them have planets. In our Galaxy if one out of 1,000 stars has a planetary system, then 200,000,000 (20 crore) planetary systems will be there. If only one per cent of these planetary systems has habitable, life-sustaining planets like our earth, then 2,000,000 (20 lakh) inhabited planets will be available in our Galaxy itself. The American

astronomer, Carl Sagan (1934-) of Cornell University, estimates that there may be as many as one million (10 lakh) advanced civilisations on the planets around the stars in our Galaxy alone. He has proposed that "certain psychological needs (are) met by belief in superior beings from other worlds" and cautions against dismissing the extraterrestrial hypotheses.



Carl Sagan.

The Universe is thought to contain more than 1,000,000 galaxies. There is, therefore, a likelihood that thousands of millions of

planets with some life forms are there in the Universe.

Some people from various walks of life have reported sighting flying saucers or *unidentified flying objects* (UFOs). They feel that the UFOs sometimes visit us. But the UFOs are either unwilling to communicate with us or are unable to do so. Although scientific committees also investigated these reports, these could not be ruled out altogether. One question still remains open, "Are the UFOs visitors from outer space, or are they just creations of some imaginative minds?"

The Pioneer 10 and 11 spacecraft launched by USA in 1972 and 1973, respectively have carried two plaques containing messages for the extraterrestrial civilisations that they might meet some day. Each plaque shows a map of the solar system, the location of the sun, a man and a woman.

The Voyager 1 and 2 spacecraft of USA, launched in 1977, which have now left our solar system, also carry long-playing records containing electronically recorded pictures of the earth, spoken greetings, sound effects and music from around the world. It may take millions of years for these spacecraft to be intercepted by any civilisation.

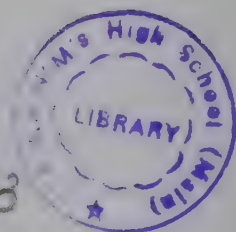
A large number of radio telescopes have been combined in many parts of the world to listen to radio signatures of intelligent beings outside the earth. But luck has not favoured the listeners till now.

The world's largest individual radio astronomy dish at Arecibo in Puerto Rico is not only listening but has been sending coded messages from the humankind to our probable fellow beings elsewhere in the Universe. No contact has yet been made.

But the search is continuing and with ever increasing enthusiasm. Nobody as yet knows whether we are alone in the Universe. If one day it becomes possible for man to contact an alien civilisation, man's perspective of the Universe will change entirely. Finding intelligent life elsewhere in the Universe will unquestionably be the most important discovery in the history of the world.

If that happens, man will no longer continue to be the master of the Universe and no more will he be alone in the Universe!

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Glossary

Billion - A thousand million--1,000,000,000.

Camera - A device for taking photographs. It consists of a closed box containing a plate or a film on which an image is formed when light enters through a hole or a lens.

Constellation - A group of stars grouped within an imaginary line. Constellations are generally named after an animal or an object.

Cosmic - Of, from or relating to the cosmos.

Cosmologist - A scientist who studies the science of the nature, origin and history of the Universe.

Cosmos - The Universe as a whole is called *cosmos*.

Electromagnetic waves - Waves that are propagated by simultaneous variations of electric and magnetic fields. These include radio waves, infrared rays, visible light, ultraviolet rays, X-rays and gamma rays.

Electromagnetic spectrum - The entire range of wavelengths or frequencies of electromagnetic radiation (waves) from the shortest gamma rays to the longest radio waves.

Globular clusters - Approximately spherical groups of about a lakh or more stars.

Gravitation - The universal force of attraction between bodies.

Gravity - The gravitational force between the earth and the objects on or near its surface or within its gravitational field.

Radio telescope - A radio receiver-antenna combination. Its component parts are designed to accept radio signals from external sources.

Spectrometer - An instrument for taking measurements of the spectra observed with it.

Spectroscope - An instrument used for creating optical spectra.

Spectrum - The waves or frequencies separated and arranged in the order of wavelengths or frequencies. For example, light is made up of several components, i.e. many colours. When these colours are separated and arranged according to their respective wavelengths, the arrangement is called a *spectrum*.

Trillion - A million million --1,000,000,000,000.

Zenith - The point in the sky directly overhead.



Man has always been fascinated by the beauty of the sky. He has wondered at the mystery of the heavenly bodies—the stars, the planets, the comets, the quasars and others. His curiosity prompted him to ask questions and find answers to what were the stars, from where did they come, and for how long would they go on shining. He has been filled with awe at space where the heavenly bodies moved. Did this space—the Universe—have a beginning and an end? Did it have a boundary, or was it endless?

Philosophers and scientists through the ages have tried to solve these mysteries about the Universe. Bits of knowledge gradually accumulated through the centuries have helped considerably in presenting a clearer picture of the Universe. Further details on this subject are presented in a lucid manner in this book for the layman.

Dr Dinesh Chandra Goswami has published more than 20 popular science and science fiction books in Assamese, besides translating ten books into this language. A student of physics, he regularly broadcasts on science from the All India Radio. He also edits and publishes a single topic popular science bi-monthly, *Dristi*, in Assamese. Presently, Dr Goswami is with the Regional Research Laboratory, Jorhat, Assam.



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